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INCINERATION OF PLASTICS FOUND IN MUNICIPAL WASTES

SYRACUSE UNIVERSITY

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INCINERATION OF PLASTICS FOUND IN MUNICIPAL WASTES

By

Syracuse University Research Corporation
Syracuse, New York

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FOREWORD

Man and his environment must be protected from the adverse effects of pesticides, radiation, noise and other forms of pollution, and the unwise management of solid waste. Efforts to protect the environemnt require a focus that recognizes the interplay between the components of our physical environment--air, water, and land. The National Environmental Research Centers provide this multidisciplinary focus through programs engaged in

- studies on the effects of environmental contaminants on man and the biosphere, and
- a search for ways to prevent contamination and to recycle valuable resources.

In an attempt to solve the problems involved in solid waste disposal, this study investigated the effects of incinerating plastics on air and water environments. Combustion efficiency of plastics was determined in several types of laboratory incinerators.

A. W. Breidenbach, Ph.D.
Director
National Environmental
Research Center, Cincinnati

"Benjamin, I've got something very important to tell you. It's a word that will change your life.. Plastics........ Plastics."

From the screenplay, "The Graduate"
Directed by Mike Nichols (1965).

".....the production figures [for plastics] zoomed in 40 years from 50 million lb. in 1929 to 18 billion lb. in 1969.........It is obvious that plastics production will [exceed] 22 billion lb. [by 1975]..............."

From "The decade that was,"
Modern Plastics, Feb. 1970, pg. 104.

"Our only hope is that sooner or later our whole society gets so plastic that we can throw it out."

- Mason Williams -

FCC Report, pg. 119
July 22, 1969.

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INCINERATION OF PLASTICS FOUND IN MUNICIPAL WASTES.

Research Grant No. EC 00304

SUMMARY

The purpose of this project was to determine the combustion efficiency of plastics when burned in several types of laboratory incinerators. These laboratory units were designed to simulate the primary flame zones of municipal incinerators. The parameters of efficiency considered were: (1) Percent of material consumed, (2) the chemical "cleanliness" of the gaseous effluent, (3) the rate of production of flyash, and (4) the more obvious environmental effects of the gaseous effluent, flyash, and residue-ash.

This was not a study in combustion theory nor was it a detailed chemical or toxicological exercise. It was primarily an attempt to quickly rate the common plastics relatively, using the criteria of ease of safe and economical incineration.

Several pure resins were burned individually in several laboratory incinerators. Also, several mixtures of plastics and a garbage recipe were burned. The resins burned were: polyethylene, polystyrene, polyvinyl chloride, and polypropylene resins, pure and wood-flour filled urea-formaldehyde, Barex 210, acrylonitrile-butadiene-stryrene (with less than 1% Cl^-), styrene-acrylonitrile, pure and wood-flour filled phenolformaldehyde, melamine, polycarbonate, and polyurethane in rigid foam, rope and glue formulations. Results are presented here from analyses of the effluent along with the effects of each effluent on rats and plants for one- to eight-hour exposures.

When there were high enough temperatures and adequate premixing of combustion air streams with the pyrolysis products, the pure or mixed plastics (except PVC) burned with apparently cleaner, less hazardous effluents (in acute exposures) than tested "natural" products such as coffee, sawdust, or rice. There were fairly definitive thresholds of afterburner temperature and air/fuel ratios for the windows of safety (the ranges of temperature or A/F ratios for which there was no apparent damage to test animals or plants). These "windows" appeared to be more narrow for plastics than for tested natural products.

We conclude that: (1) plastics-rich refuse is best consumed when the flame is not attached to the waste being pyrolyzed. This condition can be achieved by use of, for instance, starved-air primary chambers that are followed by mixing with air and then combustion, or by relatively high velocity crossfire or underfire air. In this latter case the fluid velocity near the surface must exceed the flame velocity. (2) In general, plastics are more likely to exhibit flash volatilization. Therefore, even though they are part of a solid waste stream, in an incinerator they exhibit many of the characteristics of a liquid fuel. It follows that they are more configuration - sensitive, especially near the region of the first flame. (3) When burned properly, plastics (except PVC) are not an inordinate source of toxins. When burned improperly, the effluents from some plastics were hazardous to a variety of plants and animals. (4) There seem to be three categories of plastics. The first class includes polyethylene, polystyrene and polypropylene and represents more than 75% of the plastics produced or incinerated. When burned properly, they yield very clean and innocuous effluents. When burned improperly, usually there is increased soot and occasionally sharp increases of CO. With the exception of the CO, they seemed to pose no hazard in acute exposures. The second class contains the thermosetting resins and some of the nitrogen-containing thermoplastics. If burned properly, these also gave clean and innocuous effluents. However, when burned under conditions that were less than optimum, they often yielded effluents which included hazardous concentrations of aldehydes, CO, ammonia, nitrogen oxides, and cyanides. The most hazardous and most sensitive of this group seemed to be urea-formaldehyde. The third class is dominated by PVC, which yielded hazardous and corrosive effluents no matter how burned. Where possible, this material should be incinerated with pretreatment to remove the chloride, in such a way that HCl does not reach high temperature zones of the incinerator, or escape to the environment.

INTRODUCTION

The purpose of this research grant was to study the effects of the incineration of plastics on our air and water environments. To this end, we have tested twelve pure polymers or copolymers as well as some mixtures of plastics with dilution of the inlet stream by cellulose.

The peculiar burning characteristics of some plastics cause them to be inordinately troublesome in incineration processes, with respect to both the incinerator itself and its environmental hazard.* In municipal trash, plastics account for less than 5% of the total [1]; yet they contribute much more than their 5% to the corrosion of metallic portions of the incinerator [2], to the malfunction of grates and to air pollution hazards resulting from incineration, especially when "incineration" means merely "open burning" [3]. The present research has indicated that some plastics are innocuous, some just bothersome, some potentially hazardous to health when incinerated. Some of the potentially hazardous materials can be rendered harmless by proper burning.

---

*Throughout this report the word "hazardous" denotes the presence of toxic materials in high enough concentrations to cause visible damage to any part of a test animal or plant. Therefore, a "toxic" gas may not be present in sufficient concentrations to create a "hazard." The "danger" of a hazard is necessarily left as a matter of interpretation, often by newspapers or faculty clubs.

Most of the present work has been directed to the question, "How is it possible to incinerate this resin with minimum expense and/or hazard?" We felt it most important to find experimentally a "lower bound" of expected hazard for the resins tested. Therefore, the reader should keep in mind that our methodology may yield fairly idealized results. As shown by the off-optimum tests, some resins have a higher potential hazard than the idealized tests indicated.

The research that has been done on the effects of burning of plastics on the environment includes fire-hazard studies (for example, Dufour [4]). European and American literature dealing with the incineration of plastics has emphasized PVC [5-8]. It would seem that so far, arguments about PVC have ended in a draw. It is generally agreed that HCl emission must be controlled to protect vegetation [3, 6, 9, 10] and the incinerator itself [1-3, 7]. Industrial hazard studies concerning plastics have been accomplished by a number of people, including Leong and MacFarland [11]. MacFarland's view of toxicology methodology as applied to air pollution studies is particularly helpful [12].

Studies of premixed flames from plastics seem to have been initiated by concern for the burning patterns in hybrid propellant rockets. Plexiglass, polystyrene and polyethylene were burned as simulations of solid fuel propellants [13-15] to determine regression rates and aerodynamics within the porous medium. Although the emphasis of these research programs was not particularly environmental, it would seem that incinerator design can profit not only from the burning patterns observed, but also from some of the ingenious test models used.

Another area of study of premixed flames from plastics has involved the destructive distillation of materials, followed by the collection of reusable fractions, and a burn-off of the gases that pass totally through the column. This is commonly utilized in the "Lantz process" and has been studied quite thoroughly by a number of people, including Hoffman [16]. The air pollution potential of this method is relatively small. *In situ* pyrolysis with premixing and burning has been studied for use with gas turbines [17]; the "Torrax" and "Meltzit" high temperature incinerators are also based on this two-step process. Basic studies of simple premixed flames are summarized in the book by Lewis and von Elbe[18]. The recent work by Lewis [19, 20] concerning controlled-air incineration of hydrocarbons represents a good start in fundamental studies of turbulent, premixed flames involving pyrolysis products from various materials, including plastics.

The other extreme, candlelike burning, has been studied more extensively. For example, note the excellent, careful work of Burge and Tipper [21] with polyethylene and polymethylmethacrylate. They present in some detail the temperature and composition distributions within a flame. Their results and discussions are very useful in any speculation about the origin of toxins in open flames. Martin [22] studied candleflames of polyethylene, polymethylmethacrylate, chlorinated polyethylene, teflon, and several less important polymers in a variety of atmospheres. This is also a careful and complete work.

Vari-Systems, Inc. of Cleveland, Ohio [23], has compiled a brief but useful list of the burning characteristics of the important resins. A more detailed overview is available from Batelle, Columbus [24] in a report sponsored by the Society of the Plastics Industry, Inc. Takuma Boiler Manufacturing Co., Ltd., has developed an incinerator in the 100-ton per day range for consumption of plastics with waste heat recovery [25]. It utilized NH_3 in the pretreatment stage for removal of HCl. This concept of incineration is encouraging to low-cost improvement of the environment near incinerators.

European development of technology for dealing with high Cl^- waste also sounds impressive. The increasing use of rotary kilns or lower temperature grates along with careful control of temperature and fraction of O_2 at water walls has greatly reduced corrosion problems [26-28]. Lime has also been used, along with scrubbers. This has represented a great deal of expense and effort just to tolerate slightly higher Cl^- levels.

The principal recent U. S. studies of the behavior of plastics in large incinerators have been done by Kaiser [29] and Miller [30]. Kaiser's work focused on corrosion and flue gas testing, whereas the work by Miller, et al., concerned only corrosion. These works have shown some plastics to be a problem to the life of some incinerators, and by implication to the environment. The importance of these studies stems partially from their use of large commercial apparatus, which tends to average out the effects of various flame configurations. The work by Miller indicates that there is a strong synergism between the various compounds passing through an incinerator as they attack metal parts, e.g., SO_2 corrosion is enhanced by the presence of Cl^-, and the presence of a slag deposit encourages corrosion by both of these. This corroborates the findings of Faessler, et al. [31] and Rasch [32]. Kaiser found in his recent study that increasing the proportion of PVC in refuse by 4% for only two days produced slight damage to the grates of a particular 200 ton/day incinerator. In the absence of scrubbing, the Cl^- fractions jumped from 600 ppm to 2000 or 3000 ppm as the PVC was added. It seems that damage to and by an incinerator is somewhat dependent on the configuration of that incinerator.

Synergism between the damaging gases occurs in the environment as well. This greatly complicates any toxicological or ecological analyses. For instance, Cornish and Abar [5] found possible synergistic effects between CO and HCl in their studies of the effects on rats of PVC pyrolysis (in air) products. We have found tentative evidence that pre-exposure of rats to CO creates a temporary partial buffer against the hazardous effluents from urea-formaldehyde.

The proposal for this work was submitted in 1967. Since then, plastics have been introduced to many more aspects of everyday life, to a much greater extent than we ever expected in 1967. Plastics are useful, versatile materials. They are also rapidly becoming more and more prevalent in solid waste streams, not only in sheer quantity, but in diversity of types, forms, etc. Because of their diversity, they are not easily sorted. Thus, landfill and thermal destruction (including incineration, fractional distillation or thermal recovery) are the presently economical methods of "disposal" of plastics that are already part of the mixture of materials called trash. What happens to the plastic and the environment when the material burns?

PROCEDURE AND APPARATUS

Criteria for design. The composition and toxicological hazard of both the ash-residue and effluent gases from burning plastics were strongly dependent on the characteristics of the resin - gas interface, the nature of the flame front, and the geometry, temperature and turbulence in the afterburner. Whereas each tested polymer had certain distinctive incineration characteristics, we found that the potential hazard of most plastics was more a function of the geometry and burning constraints than of the material being consumed. For instance, when burned under near-optimum conditions, polyethylene, polypropylene, polystyrene, urea-formaldehyde and Rice Krispies® all had no measurable effect on plants and animals during 8-hour exposures, and did not damage the incinerator. However, off-optimum burning yielded very different results. If the afterburner temperature was reduced to about 1200°F the effluent of urea-formaldehyde became very hazardous and corrosive; for polystyrene the "threshold" was about 1300°F and the effluent was not nearly as hazardous. Each material had an afterburner threshold, but at different temperatures. (PVC was relatively hazardous even when burned under optimum conditions.) Therefore, because of the great variety of possible incinerator configurations, and our limited time, we focused on furnace designs and combustion configurations which were as clean-burning as possible.

For most of the tests reported here the materials were burned under nearly optimum conditions. This implies: (1) At least 110% theoretical air premixed with the pyrolysis products of the burning plastic; (2) the existence of a turbulent flame, usually attached to a surface other than the fuel; and (3) a sufficiently high afterburner temperature and proper configuration. In our tests, the gas down-stream of the flame front was usually exposed to a 1700°F alumina tube for about one-half second.

Unfortunately, most plastic-waste will not be burned under "optimum" conditions corresponding to new, well-designed incinerators. More likely, it will be burned in dumps or in second-rate incinerators (or, worse yet, in house fires). Under these conditions some plastics yield hazardous by-products. The potential hazard is a function of the burning conditions, which may be quite unpredictable. We have found the slightly turbulent, candle-like flame without afterburning to be about the most hazardous; it also seems to be a good model of a poor incinerator or open burning. In the near future much incineration will continue to be under such conditions, in spite of cleaner, but more expensive methods being available; therefore, it seemed desirable to design some tests in that direction also.

Because of the wide range of possible test conditions, there were important aspects of our apparatus and procedure which differed from previous works. (a) As often as possible the animal or plant exposures and the chemical analytical work were done simultaneously and on-line. (Due to instrument failure, simultaneous tests were not always possible. The results of partial tests are also reported in the appendices). This helped insure that the animals were exposed to the same gas being analyzed which, in turn, was the gas being produced by the burning process. This eliminated "bagging," enriching, or attempting to reconstitute the gas, which methods tend to lose or alter components. However, this also forced the erection of a fair amount of plumbing for the interconnected system. These transfer lines were capable of removing components, e.g., HCl was readily removed by nickel, chromium and iron in stainless steel portions of the transfer lines. Therefore, the equipment was clustered as much as possible to keep transfer lines short, and glass tubing was used where possible. Techniques were developed to quickly clean and rebuild much of the system between tests, especially the transfer lines, in order to minimize "memory" effects from plastic to plastic. These connecting tubes were always kept above 125°F. (b) The effluent was kept above the dew point (125°F for most tests) until dilution by cool, dry air to about 75°F and 50% humidity (in the exposure chambers). Water was never allowed to condense and trap soluble components. There were no traps for removal of H_2O or CO_2. (c) The "fuel" was usually fed continuously by an auger or conveyer at rates of from 120 to 2200 grams per hour. (Batch feeding with a crucible or boat was not necessary, although possible). This assured us that all of the compounds of pyrolysis were present in the flame all of the time. (d) There was always a flame. Due to a lack of chemical equilibrium, a gas mixture downstream of a flame may differ from a gas mixture without a flame given the same reactants and the same final temperature. So we were closer to actual incinerator conditions in this regard.

In spite of our attempt to simulate actual possible incinerator conditions, our results should still be viewed as representative of a laboratory-scale and laboratory-configured incinerator. If our model incinerators were scaled up to larger commercial or municipal sizes, the "hazard hierarchy" of the resins tested would probably remain the same, i.e., the results reported here are best used for comparing one plastic to another.

Combustion Train and Residue Tests. The first combustion chamber was supplied with the polymer being tested plus combustion air (See Fig. 1). This chamber could be operated with 0% to 300% theoretical air (usually 150%), and usually it had an average temperature between 1500°F and 1900°F. We employed three basic modes of burning in this primary zone. The first required a continuous supply of fuel and air as shown in Fig. 1, with the fuel exposed directly to the combustion air. This was representative

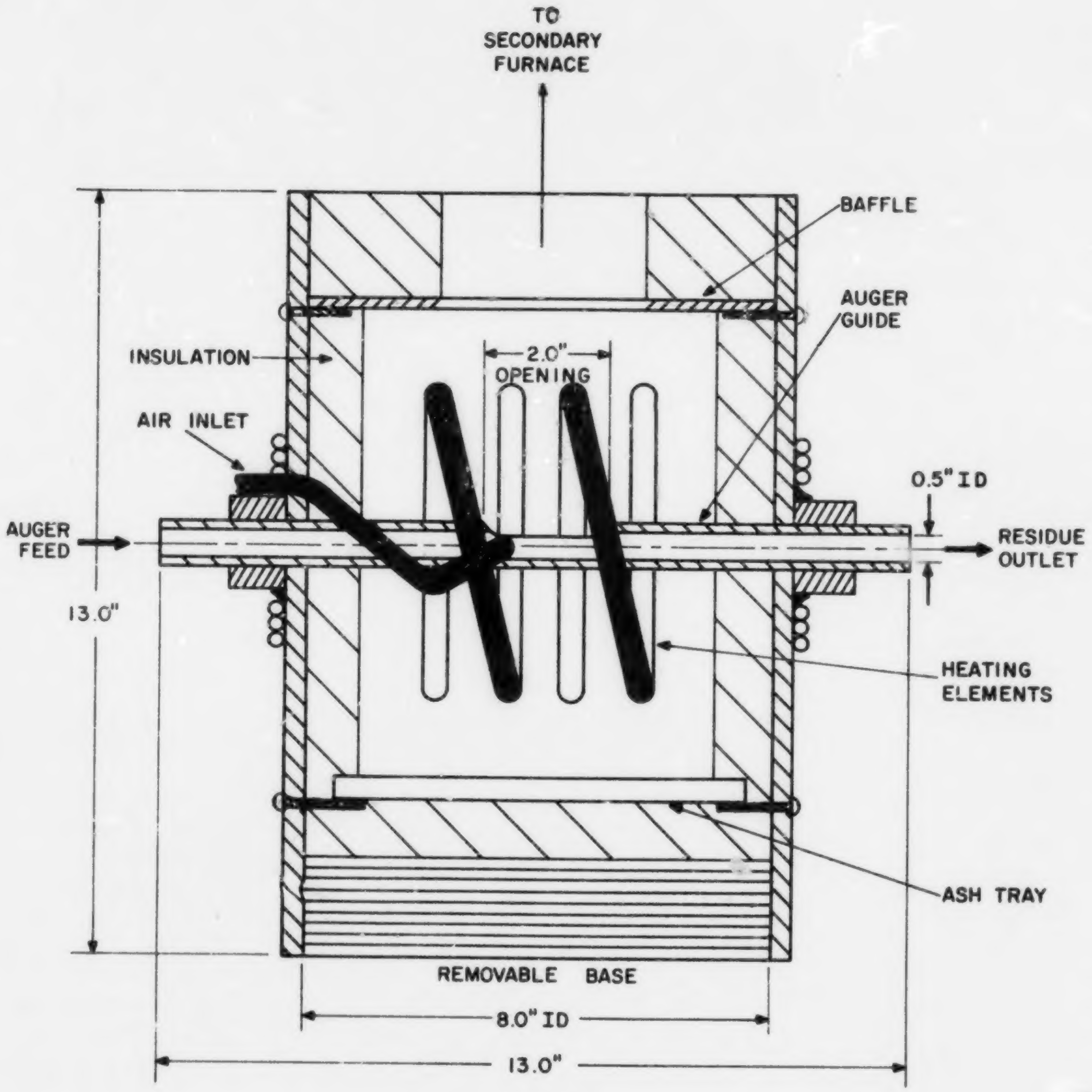


Figure 1 Continuously-fed primary furnace. For tests involving anaerobic pyrolysis followed by combustion, the auger guide has no opening in the flame region except for several small holes drilled in its top.

of usual incineration processes, employing a "one-step," heterogeneous burning configuration in which the fuel is pyrolyzed while its surface is exposed to the combustion air. Whenever possible, the conditions were kept such that the flame did not attach to the fuel. The second mode was also continuously-fed, but was a "two-step" process involving pyrolysis of the fuel in the absence of combustion air, followed by homogeneous combustion of the pyrolysis products. Throughout the rest of this report the first mode will be referred to as "aerobic" burning and the second mode, "anaerobic" burning. The third mode was batch-burning, where combustion air reached the fuel primarily by diffusion.

The fuel consisted of small particles of the polymer in question fed to this chamber by an auger or pneumatic conveyor. The heating coils in the primary furnaces were used for ignition and maintenance of furnace temperature. These coils initially received enough power to bring the interior of the static furnace to about 1000°F. Fuel addition brought the temperature up the rest of the way. In some tests (such as polystyrene), the combustion heat was high enough to sustain temperatures above 1700°F without any electrical input, in which case, the electrical power was turned off. The temperature of the primary furnaces was not controlled except by a Variac setting. By contrast, the afterburner temperature was controlled to within 50°F by a simple controller.

Alternately, if batch tests were desired the auger assembly could be easily removed and a simple crucible holder put in its place. The ash from the expended fuel, if there was any, was collected and given a proximate analysis.

Immediately downstream from the first burning chamber was another air injection port. This additional air source was adjusted to help control the fraction of excess air as well to vary the degree of turbulence in the afterburner (Fig. 2, 3). Normally 30% of the combustion air entered here. The afterburner or secondary chamber was a 36" long vertical tube furnace. There were two tubes used; one 3" I.D., the other 4" I.D. The temperature of the tube was usually held at about 1800°F. Polystyrene tended to drive the temperature of the afterburner to about 2000°F. Occasionally, temperatures less than 1800°F were set to observe off-optimum burning of the plastic, or were created by the failure of an afterburner element. The reported afterburner temperatures are time averages of the temperature of the center tube over the span of the exposure of test plants or animals.

In the primary furnace, the combustion air came from the same source as the purified air that was fed to the control rats and plants. In the first design, air entered the combustion chamber as a jet just over the exposed burning plastic. Under certain burning conditions or with certain plastics, the fuel caused the auger to bind in its guide to the extent that no feeding took place. For some materials, especially the finely ground resins, this problem was solved by the use

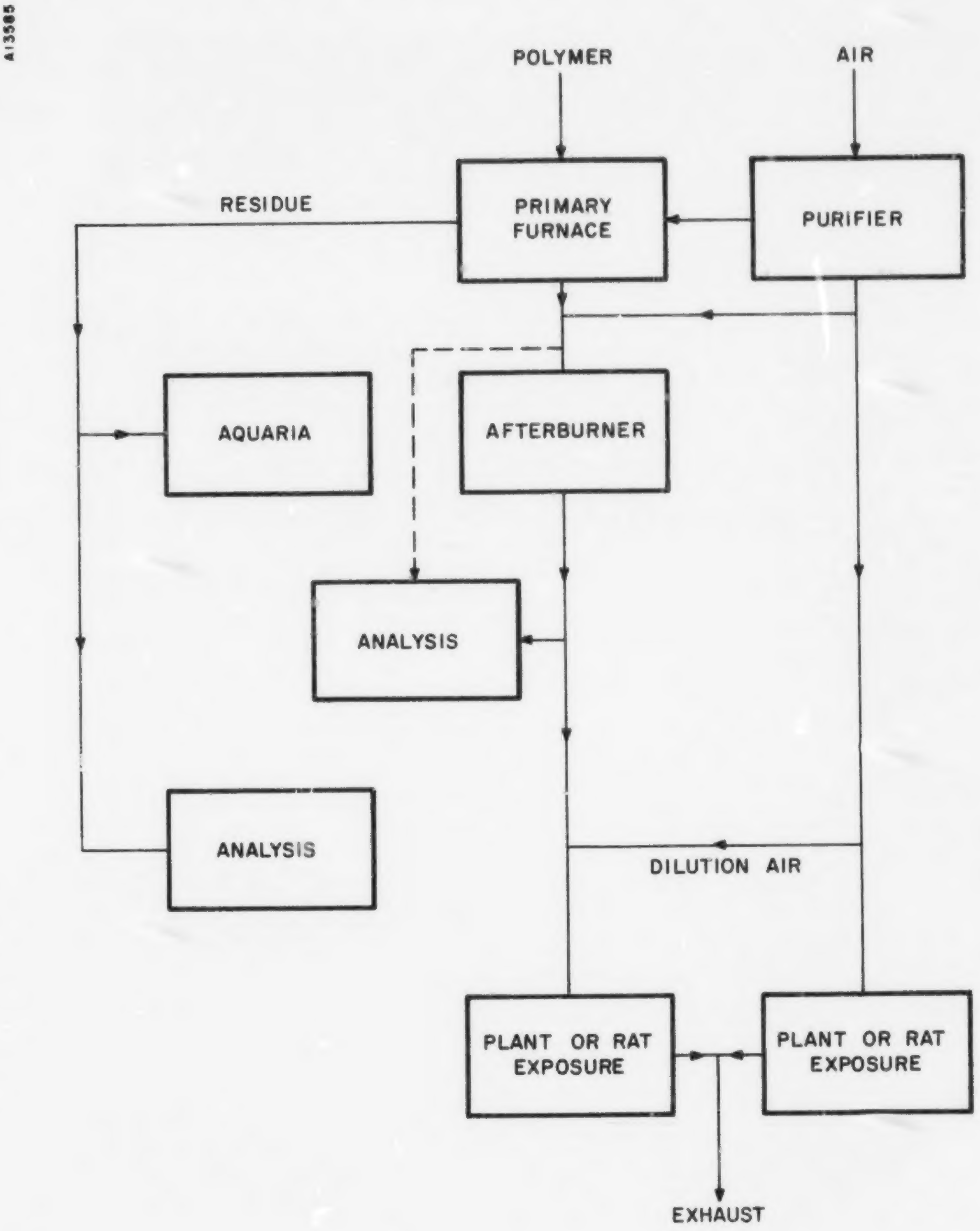
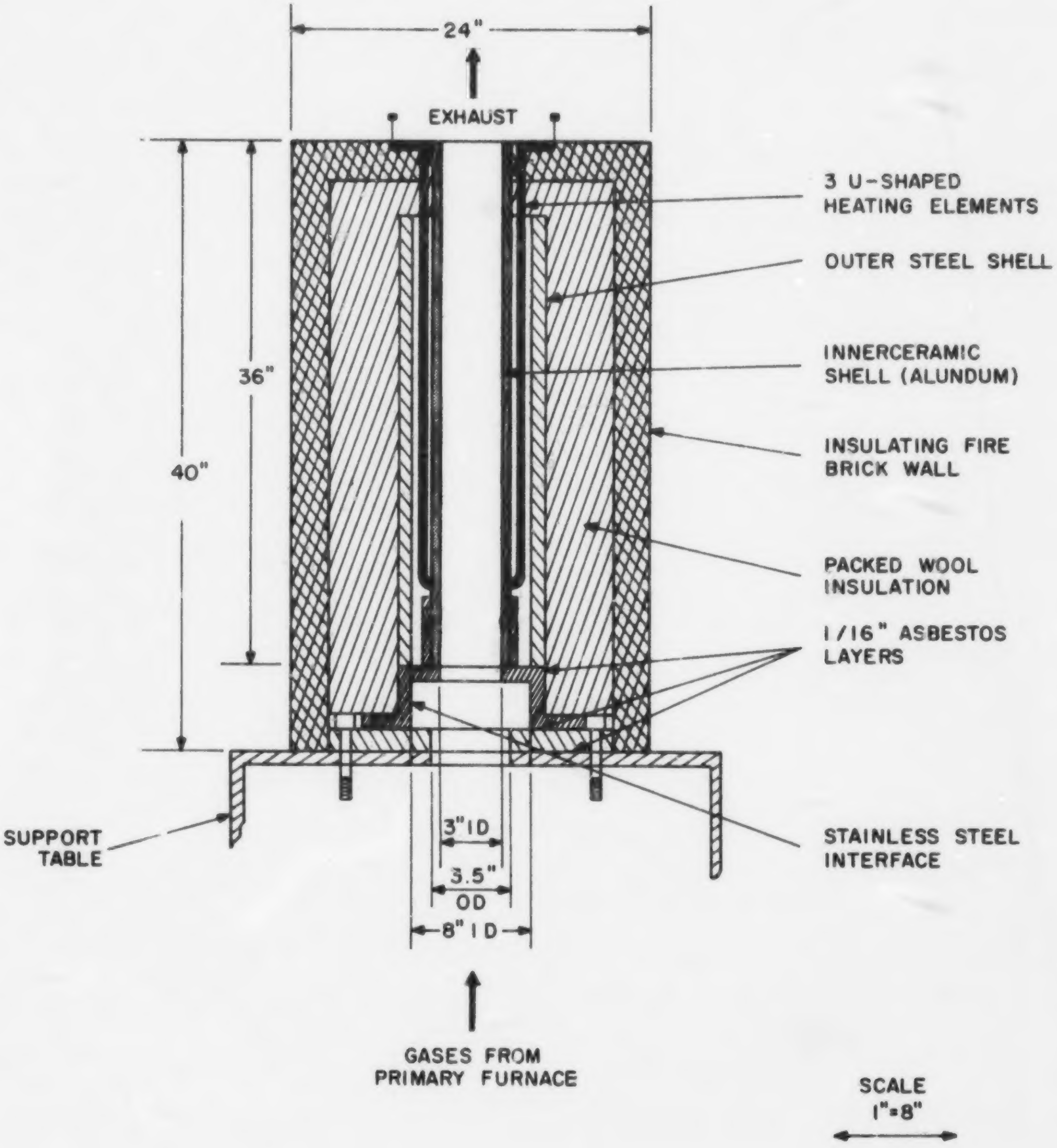


Figure 2 Schematic Diagram for Overall Test Apparatus for Study of Incineration of Plastics.


24"
EXHAUST
36"
40"
3 U-SHAPED HEATING ELEMENTS
OUTER STEEL SHELL
INNERCERAMIC SHELL (ALUNDUM)
INSULATING FIRE BRICK WALL
PACKED WOOL INSULATION
1/16" ASBESTOS LAYERS
STAINLESS STEEL INTERFACE
SUPPORT TABLE
3" ID
3.5" OD
8" ID
GASES FROM PRIMARY FURNACE
SCALE 1"=8"

B15334

Figure 3 One of the Secondary Furnaces

of a pneumatic feed. In this design, the fuel was brought to the edge of the primary furnace by an auger and blown into the hot zone by the first combustion air source (Figure 4).

We were still unable to feed polycarbonate or phenol-formaldehyde glue satisfactorily. Also the corrosive combustion products of certain plastics, such as PVC, drastically shortened the life of the heating elements; and replacement of a blown element required time-consuming dismantling and reinstallation of the furnace. Therefore, another primary furnace was designed and built (Figure 5). A horizontal auger was still used to feed the polymer into the burning zone; however, the diameter was twice the size of its predecessor - now 1" diameter. It also had the ability to use our newly developed air-auger feeding mechanism. In this design the polymer, once it entered the hot zone, fell downward through the underfire-air inlet stream. For finely ground resins, this is where much of the combustion occurred. Since the material in this area was usually in a partial liquid and partial vapor phase, the fall of the material helped insure positive premixing of the air and fuel.

Most remaining combustible gases were burned just above the overfire-air inlet after they had passed through the orifice around the cone. This second flame usually attached to the top of the orifice. From here the gases immediately entered the afterburner.

These three designs were checked for interchangeability so

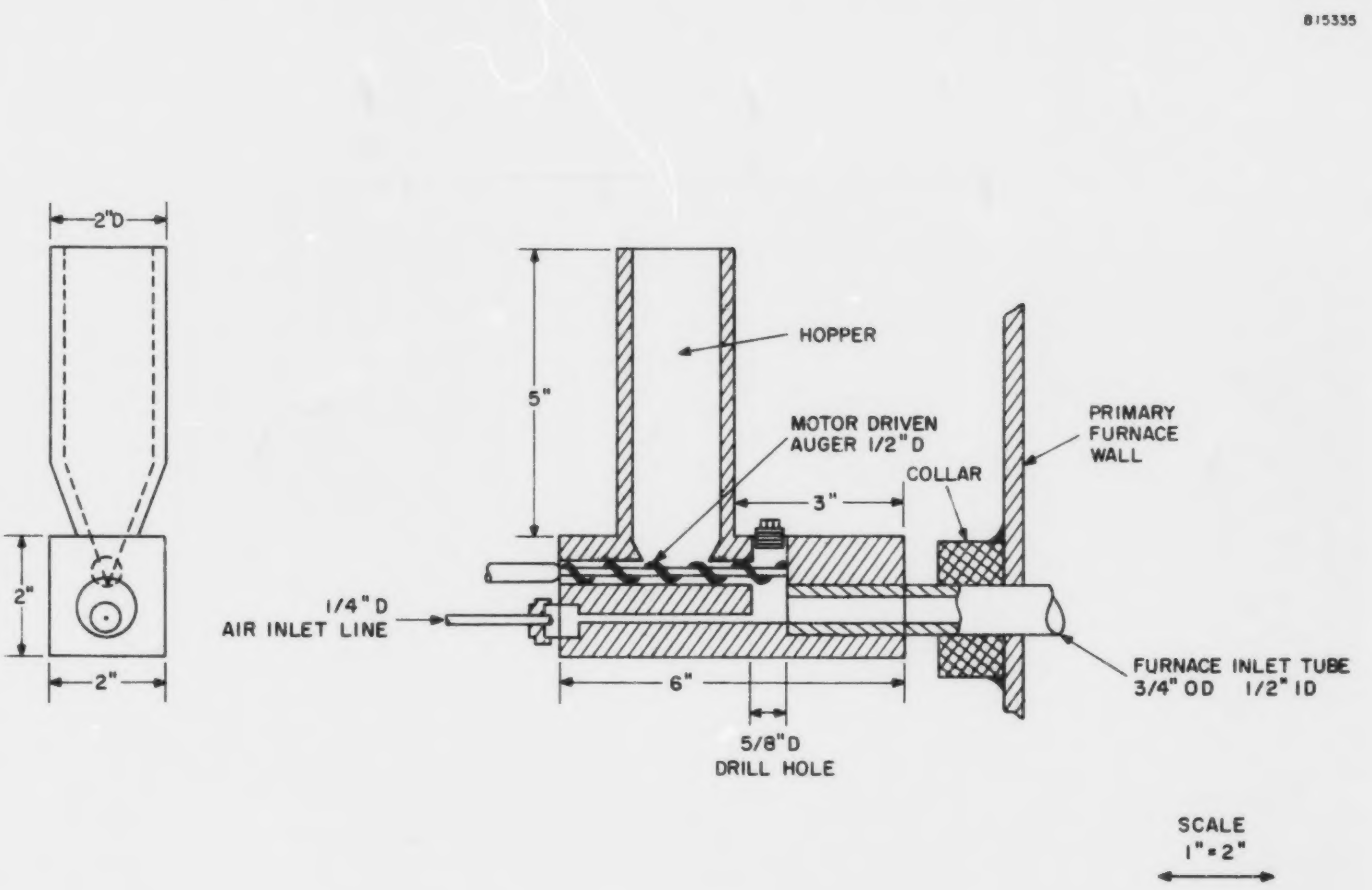


Figure 4 - Air-Auger Feeding Mechanism

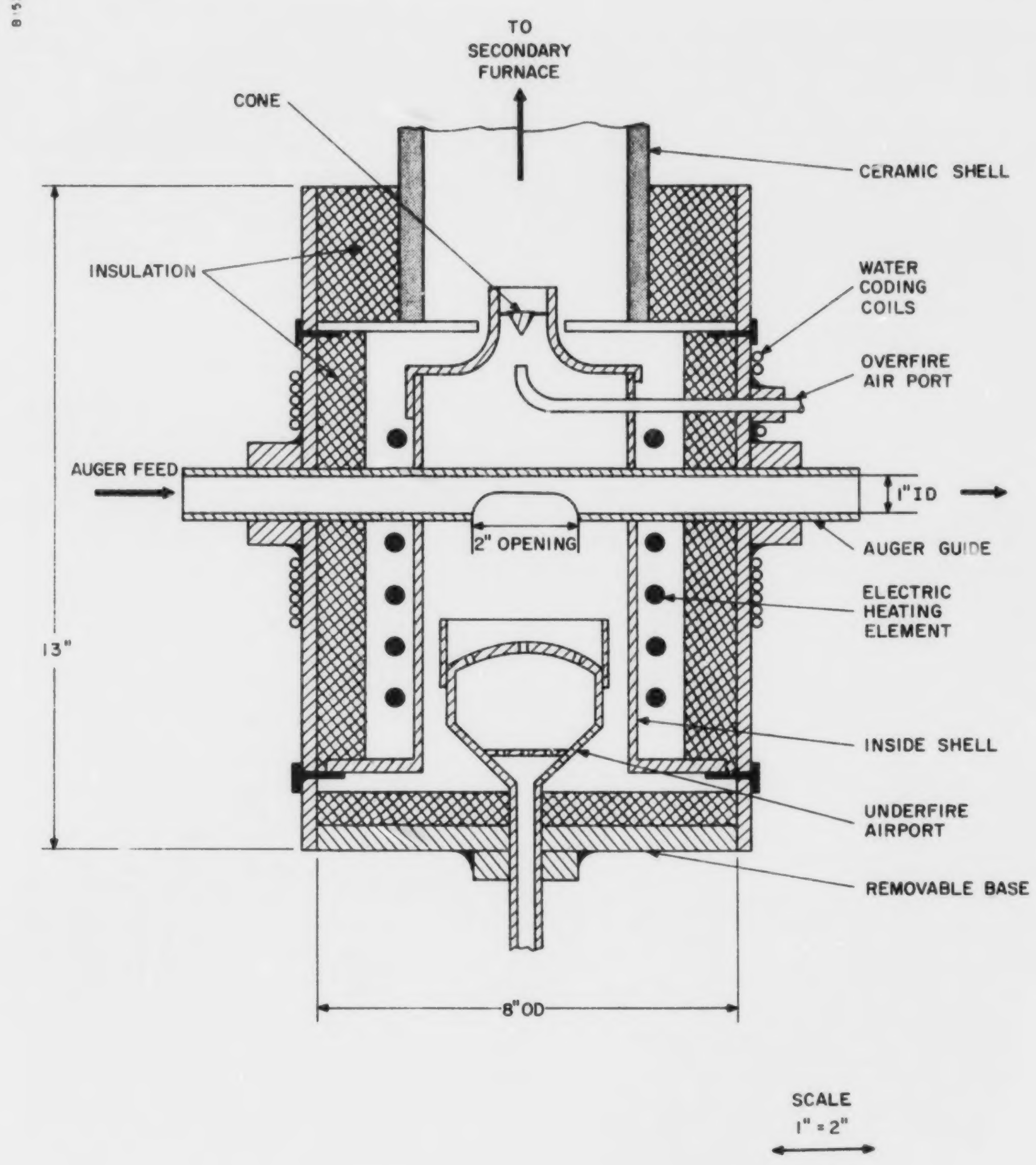


Figure 5 Second Primary Furnace Design

that we could be fairly sure that all three were yielding nearly the same toxicological results. For polyethylene, polypropylene, urea-formaldehyde, and polystyrene, the effluents and toxicological damage (or lack thereof) were the same within our overall experimental error.

Finally, for some of the mixtures, a simple "box" was used as the primary furnace (Figure 6). This was the best configuration for burning polycarbonate and phenol-formaldehyde. The effluents contained more hydrocarbons, CO, and soot, but in general the toxicological results indicated that its effluents were not much more hazardous in acute exposures than the effluents of the same mixtures using the other primary furnaces. The air/fuel ratio of this unit was more difficult to control. Fuel was hand-fed through the squirrel cage fan. Therefore, the volatilization rate was not as predictable. Also, the rate of throughput of this primary furnace design was too large for the 36" long afterburner. Whereas other tests utilized only 30 to 1200 grams of material per hour, requiring a maximum of about 600 SCFH combustion air, this hot box required about 1500 SCFH with about 5 lbs/hr. fuel to maintain ignition and burn with a minimum of soot and odor. This was too much for the afterburner to handle.

The proximate analysis of the ash residue and of the fuel itself was carried out according to the ASTM code for coal (ASTM designation B 271-64). This procedure had to be modified for the

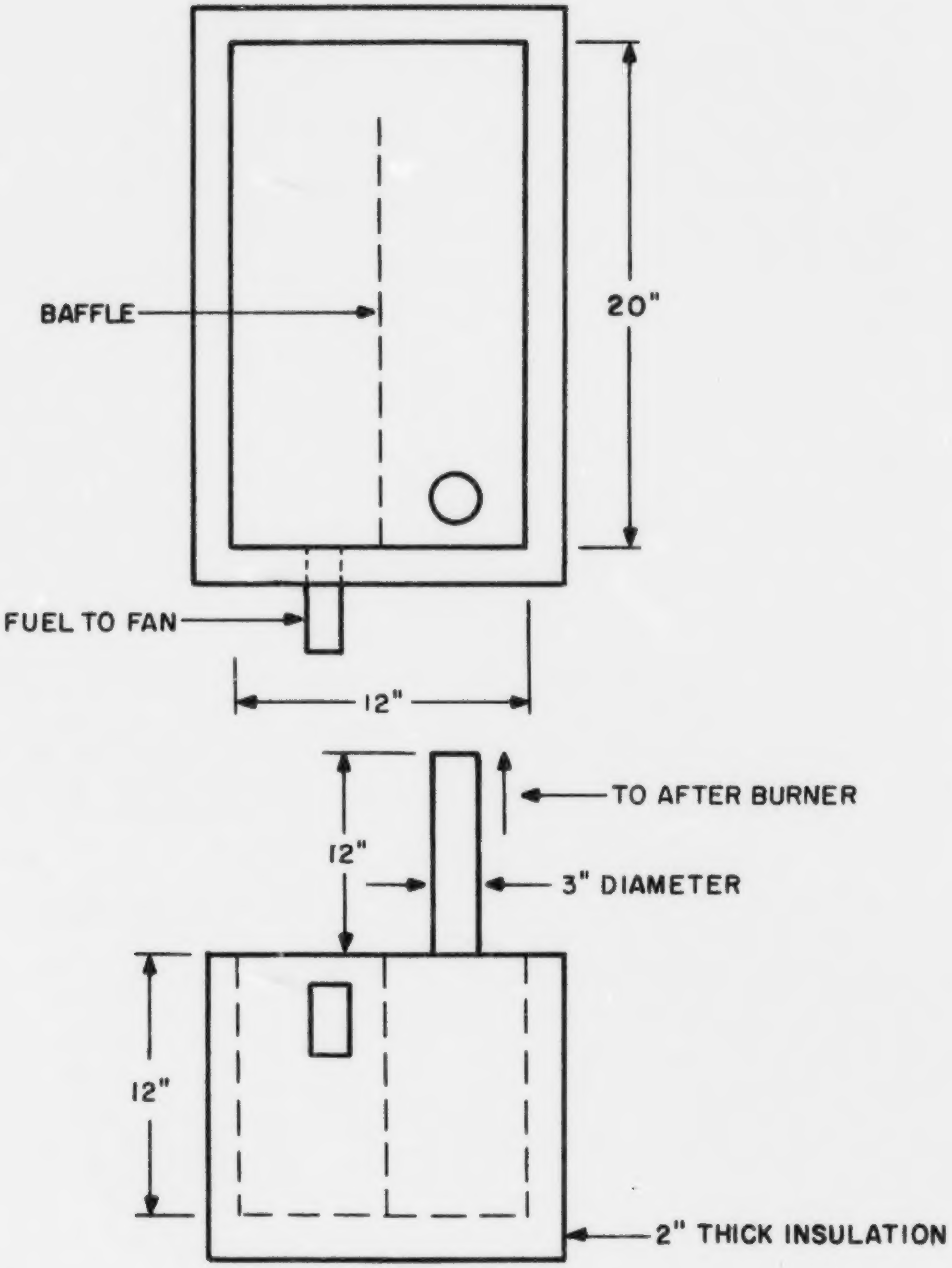


Figure 6 Pit incinerator primary furnace.

measurement of moisture and for the measurement of ash. The moisture measurement utilized a lower temperature. We used 130°F for 24 hours instead of 220°F-230°F for 24 hours as recommended by the ASTM code. In the determination of ash, we held the material at the recommended high temperature for approximately one hour after attaining the temperature of 1300°F. These two modifications were necessary to first prevent volatilization of the material and chemical reorientation of the polymer during the moisture test, and secondly to oxidize totally the refractory hydrocarbons that may form during the increase of temperature in the presence of oxygen. This procedure was successful except for two tests in which the ash-char was too refractory for even the one hour test. In these cases, we had to modify further in that the ash test was made after the volatile matter test, using the same sample, in the same crucible.

Gas Analysis. Effluent samples were drawn through a probe inserted in the center of afterburner about 6" from the top, and analyzed "on-line" by gas chromatography and mass spectroscopy. The sample temperature was kept above 130°F throughout. During several tests, we supplemented or replaced the GC-MS analysis train with a system which identified total ammonia, CN^-, CO, total aldehyde and ketone, chloride, and NO_x. The methodologies for these tests are similar to those employed by Carotti [29]. As a rough cross-check, tests were also made on the water trap that was between the Andersen particulate sampler and its pump. These tests were for total NO_x, chloride, CN^- and NH_4^+ absorbed from the effluent by this water. Because of the poor configuration of the trap and the purification of the effluent as it passed through the Andersen, these values are somewhat below the actual concentrations in the stream. These tests were conducted using the test-kits produced by HACH, Inc. [41]. A separate procedure was occasionally used for the determination of acrolein [40].

The remainder of gas from the incinerator was then cooled to about 200°F and sampled for particulate size distribution using an Andersen seven-tray impingement analyzer which was kept at about 200°F. The gas was cooled further to just above its dew point, then diluted and passed to the animal and plant exposure chambers. For batch tests, the dilution ratio was 4:1 (clean air:effluent), and for continuously fed, usually 8:1.

The limits of detectability were as follows: (1) For hydrocarbons measured by the F.I.D. of the gas chromatograph, usually 0.01 ppm equivalent CH_4. Occasionally because of electrometer drift, this rose to 0.1 ppm. (2) For CO, 8-15 ppm. (3) For NO_x, ammonia, cyanide or total aldehyde-ketone, 0.1 ppm. (4) Total chloride, 10 ppm.

These numbers also constitute the lower limits of accuracy. Precision errors were typically 5% during a test, and accuracy errors were less than 20% using calibration gases.

For particulates, the limit of measurement was 0.001 mg flyash/gm of fuel. The precision error was never measured. For an initially clean apparatus, this error is probably considerably less than the accuracy error which we estimated to be less than 50%.

Because of the geometry and materials used in our system, it will be difficult to evaluate the effect of accuracy errors for particulate and total chloride measurements. In general, we feel that measured total chloride was always less than the chloride present because of the extraction of the chlorides by the transfer lines. This extraction was by reaction with the transfer-line materials as well as with the materials (soot, etc.) deposited on these surfaces.

In general, the particulate errors will be such that measurements probably yield higher quantities than present. The Andersen sampler not only collected the flyash entering it; it also collected the particulate created within the sampler by reaction of gases such as HCl, NH_3, HCN, etc., with the aluminum surfaces of that sampler. Therefore if the particulate readings are in error, they probably reflect a higher concentration of flyash than was actually there.

Biomonitoring. The possibility always exists that the products of combustion of plastics may lead to synergistic toxic effects which are not predictable from chemical identifications alone. It follows that separate biomonitoring studies were in order and we used these in conjunction with the gas analyses. Most plastics yielded effluents whose several potentially lethal components were very dilute, (except for HCl from PVC) i.e., we were usually working with multicomponent gases, each component of which was present in concentrations well below its lethal dosage.This has given rise to several questions, the most fundamental of which is: What acute exposure studies are adequate for this type of initial "pollution screening" work? Our feelings at this point are that (1) detailed studies of one or two species are not adequate, (2) they may still be useful, (3) only statistically obvious results should be taken seriously, and (4) supplemental studies of gress behavioral changes in a larger selection of phyla would be helpful.

The principal organisms employed in our biomonitoring system included specific pathogenic-free Sprague-Dawley rats, and various land plants. All were observed for the effects of effluents upon their immediate, short-term viability and growth rates, and changes in locomotion.

The effluent to which the plants and animals were exposed came to the chamber from the afterburner via an overhead line, which was kept at a high enough temperature to prevent condensation of water. At the junction of this line with the chamber, the effluent was diluted with purified compressed air. The purpose of this dilution air was strictly to reduce effluent temperatures while preventing water to condense. If water did condense, we would "lose" some water-soluble compounds. A minimum of air was added in order to maximize the concentration of toxins. The relative humidity was kept between 45-50% and the temperature at about 78°F. Both humidity and temperature were monitored.

When placed in the chambers, each rat was in its own stainless steel 1/2" mesh cage. These individual cages prevented fighting or crowding and allowed the rats freedom of movement, all of which made observation easier. These cages also reduced cross-contamination. We had considered using the method developed by Cornish and Abar [5] which confines the rat so that only the nose is exposed for inhalation toxicity studies. However, our emphasis was on biomonitoring, not toxicology. Therefore, the exposure of the whole animal in its individual cage seemed more appropriate.

Exposure Chamber. The exposure chamber was 36" long by 18" high and 12" deep (Figure 7). The chamber was vertically divided in half by a 2" wide intake manifold through which the effluent gas was evenly distributed throughout both halves. Each half would accept up to four flats of plants and eight rats.

At the bottom of each half, there was a fan-driven exhaust manifold. The chamber was constructed from stainless steel except for the top, which was 1/4" thick glass plate. Each half of the chamber had an access door, which contained a 6" x 8" glass window. These windows permitted observation of the exposed plants and animals. The glass top and front were also useful in supplying adequate light

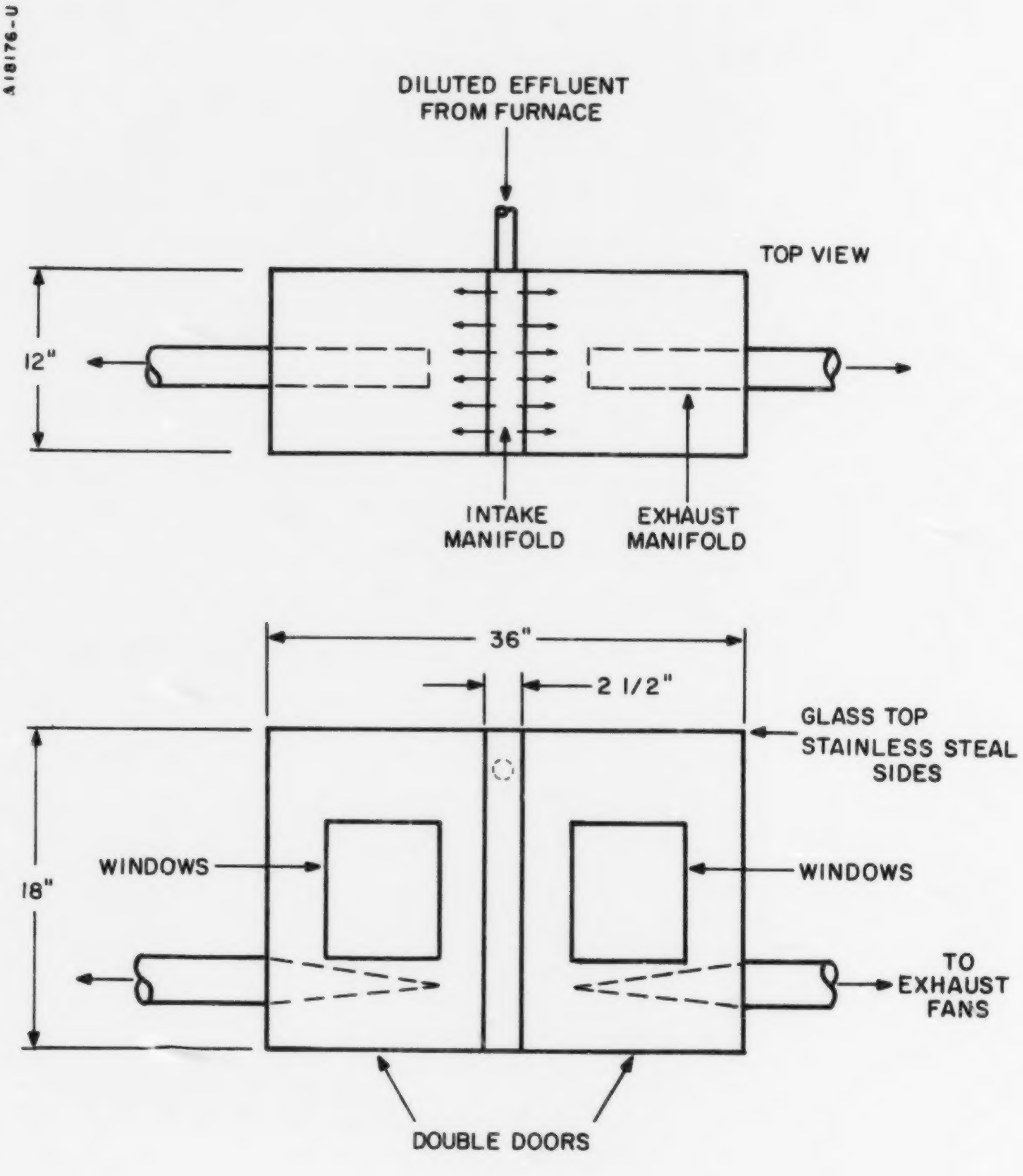


Figure 7 Exposure chamber.

during plant exposures. A control chamber of similar design was used in parallel.

Procedures. Male*, specific-pathogen-free, Sprague-Dawley rats (weighing between 200-300 grams) were the animal monitors employed.

For one week prior to exposure, these animals were kept in a climate-controlled room (72°F, 50% relative humidity) in individual cages. Each cage had wood chips as bedding. All rats were fed Purina Laboratory Chow and water *ad libitum*.

These animals were examined for gross reactions, changes in blood and urine** chemistry and pathologic changes.

Two days prior to a test 0.3 ml of blood was drawn from the tail of each rat. From these samples, total hemoglobin (Hb) [33], carboxyhemoglobin (HbCO) [34], and white blood cell count (W.B.C.) [35] were determined. Also, hematocrits were performed and the mean corpuscular hemoglobin concentration (MCHC) was calculated [36].

At the conclusion of each exposure, the above blood tests were repeated. About sixteen hours later, the rats were sacrificed for heart punctures for the determination of SGOT and SGPT enzyme levels [37] and necropsied for gross pathologic examination. Histopathologic examination was performed on selected tissues* by Microscopy for Biological Research, Ltd., of Albany New York.

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*On one occasion, we received a shipment of female rats. Since the scheduled tests could not be cancelled, we had to use the females. Tests where females were used are indicated as such.

**The urine analyzed was from pooled samples. Where urinalysis was performed, it is so indicated.

Urinalysis [38, 39] was added to the monitoring procedures late in the study at the suggestion of our OSWM Grants Officer. Where urinalysis was performed, the rats were placed in metabolism cages and fasted overnight. This was done immediately after pre-test bleeding two days before exposure and again on the night after exposure.

We continually experienced difficulty in one area of rat pathology. The microecosystem of pathogens in the bronchial tract of rats is easily upset by inhalation of toxins; it is also readily capable of yielding damage more extensive than from toxins. We found it necessary to work with specific-pathogen-free rats which had been kept in separate cages since weaning. Upon receipt, these rats were held in individual cages and kept no longer than four weeks in the lab. This turn-over helped to insure that they would not develop respiratory problems from care and handling. In spite of these precautions, histological studies indicated that many of the rats had chronic bronchitis.

Six species of plants were also used as biomonitors. These were summer squash (cucurbita pepo), Kentucky bluegrass (poa pratensis), northern green beans (phasedus vulgaris), Indian mustard (brassica juncea), alfalfa (medicago satira) and oats (arena fatua). Plants that were one to two weeks old (measured from the time they broke through the soil) were exposed for three to six hours. Because the sensitivity of these plants decreased sharply with age, we sometimes simultaneously exposed one-week old and two week old plants.

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*Where histopathological examination was performed, any remarkable results are entered with the necropsy observations.

During the exposure, and for several weeks after, the plants were observed for any gross effects as compared to control plants.

The six varieties of plants were maintained in a mixture of 1/3 sand and 2/3 potting soil. They were planted at a depth of 1/4" covered with sand and 2/3 potting soil.

The flats used were 8" long by 5" wide by 3-1/2" deep. The beans and squash were planted separately from the other, i.e., one flat usually contained beans and squash, and another flat contained bluegrass, mustard, and either alfalfa or oats.

The temperature in the greenhouse was maintained at 85°F-90°F, and the humidity at about 55%. On some summer days, the temperature rose to 100°F. The plants were watered once a day. Fixtures containing four Vitalite® 40 watt fluorescent bulbs were suspended 18-24" above the plant boxes for additional growing stimulus. Approximately the same level of lighting was maintained during exposure of the plants in the exposure chamber.

RESULTS

Overview. With the exception of PVC, classically "good" combustion constraints (high turbulence, sufficient time at sufficient temperature) implied a toxicologically clean effluent. We had expected oxides of nitrogen to be present in significant amounts when burning the nitrogen-containing polymers, especially acrylonitrile. If this had occurred, there would be no way of configuring a combustion zone to give clean effluents if N-containing plastics were present. However, nitrogen oxides were usually below 1 ppm while burning these materials. Moreover, acrylonitrile seemed to stabilize the burning of styrene (styrene - acrylonitrile burned much more easily and cleanly than styrene alone); and Barex 210, which is about 75% acrylonitrile, appeared to burn easily and cleanly. Only when urea compounds were batch-burned did we see significant quantities of nitrite-nitrate.

Polyethylene, polypropylene and polystyrene yielded the least hazards or potential hazards during our tests.

A second group of materials presented no hazard only when burned properly. However, they yielded effluents that were quite hazardous to both plants and animals if the furnace temperatures or geometry were not adequate, in spite of the presence of sufficient combustion air. This group included urethane, melamine and urea-formaldehyde resins. The principal toxins were ammonia, cyanides, and aldehydes, all of which were present in significant amounts during off-optimum burns.

ABS, phenolformaldehyde and SAN were not tested in off-optimum burning, but possibly should be included in this group.

The only material tested that yielded hazardous effluents, no matter how it was burned, was polyvinyl chloride. When burned "optimally" with a supporting fuel of PE or cellulose (PVC is self-extinguishing in spite of its exothermic reaction with air) the only observed toxin was HCl, as expected. When burned in the same configuration without a supplemental fuel (but still with the furnace elements on) the principle toxins were HCl and CO. No other chlorinated plastics were tested.

The combustion, chemical, and toxicological results are listed below according to the material burned. Included in each subsection are the broad results of the burnings and then the specific results concerning combustion behavior, chemical analyses, and toxicological results. Further details are included in individual appendices for individual materials or mixtures.

Polyethylene. Low density polyethylene was used. It burned with the least difficulty and was the least hazardous of the entire set of tested plastics. It burned well in all of the configurations we used except in candlelike burning in which case it gave a great deal of soot. However, the soot problem was solved by directing some or all of the combustion air across the surface of the melted plastic, or by operating with starved air conditions, especially the "anaerobic" burning configuration.

Polyethylene was burned three times in a batch (candlelike) configuration, three times in a continuously-fed "anaerobic" configuration, and nine times in various continuously-fed "aerobic" configurations. It was burned three times as a significant part of a mixture of polymers. In addition, there were numerous occasions when this plastic was burned for only an hour or so to check out a new configuration. The material was usually burned for 6 to 8 hours for each continuously-fed test. On three occasions, the test was terminated by failure of heating elements in one of the furnaces. (These elements were a serious defect in our design, in that they were designed to operate at temperatures 200°F lower than what we normally attained.)

The combustion properties were similar to those found in polystyrene and polypropylene, which are discussed later. The temperatures in the primary furnace and afterburner were of the order of 1600°F to 1800°F for all continuously-fed tests. The flyash, though black on the plates, was transparent when viewed through a microscope. It was distributed in size as tabulated in Appendix II. There was no ash-residue whatsoever when this material was burned aerobically, anerobically or in the candle configuration.

The highest quantity of (total) flyash for our continuous burns (either aerobic or anaerobic) was approximately 0.5 milligrams per gram/fuel. Soot production increased slightly as the amount of combustion air was increased. This may be due to the furnace configurations; possibly the increased draft cooled the fuel surface and enhanced (CH) radical concentrations near the flame tip.

In the absence of faulty furnace operation, there was less than 15 parts per million* carbon monoxide. Aldehydes, nitrous and nitric oxides were below our limit of detectability. There were occasions on which we had one or two parts per million of methane, ethane, ethylene and acetaldehyde along with small quantities of C_5 or C_7 compounds. There were seldom any other hydrocarbons present in quantities greater than 0.1 ppm. Occasionally, the primary furnace was operated at a lower temperature (between 1000°F and 1200°F), and under those conditions the polyethylene was more difficult to control in terms of the chemical nature of its effluents.

The candlelike flame gave copious amounts of ethylene, soot, methane, ethane, and acetylene.

Our toxicological results for polyethylene are based on six plant exposures (two, one-hour batch tests, three, six-hour exposures with aerobic, continuously-fed burning and one six-hour exposure for "anaerobic burning"), and six rat exposures. A total of four rats were exposed to batch-burning effluents (1 hour exposures) and 9 rats (total) each for anaerobic-continuous and aerobic-continuous (four-hour exposures). The plants were totally unaffected by acute exposures, even when the air to fuel ratio was about 100% theoretical air. In one test, we burned at about 75% theoretical air for a period of about four hours and there was moderate damage to the plants.

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*Unless stated otherwise, all chemical results are stated in units of moles of trace gas per mole of effluent. (Equivalent methane for F.I.D.)

In general, the rats were unharmed by exposure to polyethylene fumes for these acute exposures. Normally their blood chemistry was unchanged from pre-control values to test values and normally the necropsies showed no internal damage. In one four-hour exposure, however, we had some enhanced hemmorhaging within the lungs. However, the histological work later showed no unusual results due to the exposure.

During one exposure, the air-fuel mixture was 75% for two hours, thus creating high carbon monoxide conditions (3000 ppm) as well as high ethylene (about 100 ppm). Even under these more extreme conditions, there was no apparent damage except for elevated HbCO. It is our impression at this time that polyethylene resin yields effluents less hazardous than those obtained from any material we tested.

Polystyrene. Polystyrene has a reputation for high soot potential, and our experience indicated that this reputation is well founded.

When the flame or furnace temperature dropped below about 1600°F, this material did tend to soot rather heavily - even when burned in more than 100% theoretical air. However, when burned in a proper configuration (high temperatures and crossfire injected combustion air), the material burned very cleanly, giving off the least soot of any of the compounds we tested, except SAN.

Polystyrene was burned two times in a batch configuration (yielding one-hour exposures for the plants and four rats), seven times in the aerobic-continuous mode for eight hours (allowing three, six-hour exposures for plants and four-hour exposures for 19 rats), and four times in the anaerobic-continuous mode for eight hours, with four-hour exposures for 14 rats and one set of plants. In addition, it was burned three times as a significant part of a mixture of polymers, as well as being used in numerous short burns to check test configurations.

The combustion results for this material are of importance because of the soot potential and because of the burning configuration problems. We found that the higher the theoretical air used, the greater the soot potential. As the theoretical air increased from roughly 80% to 360% the amount of soot increased just about monotomically (see test results of Appendix III). Fortunately, the increases occurred mostly in the larger size (settleable)particulates. Aerobic burning yielded cleaner results, in terms of generation of soot, than anaerobic burning; this may be due to the lower temperature at the pyrolysis front in the anaerobic burning configuration.

If the after-burner was allowed to decrease in temperature to below about 1300°F, soot and simple hydrocarbons appeared in much greater quantities. Even when the primary furnace temperature was held at around 1700°F the after burner had to be held above 1300°F in order to clean up carbon monoxide, acetylene and a number of heavier hydrocarbons, including benzene; the benzene was found in concentration of only two or three parts per million. The carbon monoxide concentration sharply increased to about 300 parts per million when the after-burner temperature was reduced to about 1200°F.

The material is relatively easy to ignite and has a very high heat of combustion; therefore, it is a rather valuable fuel. It is capable of generating very high temperatures. When we burned this in a mock-up of a pit burner, we succeeded rather easily in melting the steel casing.

In general, our primary conclusion on the combustion of polystyrene is that it is extremely configuration and temperature sensitive, much more so than, say, polyethylene or polypropylene. However, it is less configuration sensitive than ureaformaldehyde.

In poor configurations, it readily gives off much soot, carbon monoxide and hydrocarbons.

The chemical results are based primarily on gas chromatographic results using the flame ionization detector, the thermal conductivity detector and the mass spectrometer. There are a number of peaks in C_5, C_6 and C_7 range. The only C_6 compound is benzene; the C_5 and C_7 compounds have not been identified. When burned with too low an air to fuel ratio or too low a temperature in the after-burner, there was a tendency to give off simple hydrocarbons containing or constructed from CH and CH_2 radicals. In general the aldehydes, chlorides, nitric oxides for polystyrene were below the limit of detectability.

We suspected that polystyrene, since it is more configuration sensitive, would give off potentially more hazardous hydrocarbons than the olefins. However, we found that it was only slightly more hazardous in acute exposures to rats than polyethylene both above and below its afterburner threshold temperature.

The characteristic odor, soot and carbon monoxide disappeared when the configuration was correct, i.e., when the furnace temperature was high enough and when sufficient combustion air was coming in at the right angle. None of these cleaner combustion conditions yielded observable damage in the rats with the exception of one four-hour test.

In this test, there seemed to be an accumulation of gray matter in the bronchi and lungs of the exposed rats; all the constraint parameters of the test (temperature of furnaces, effluent chemistry, etc.) were similar to other tests in which no damage was observed. The histology revealed no unusual findings in the lung tissues. It should be noted that this group of test rats was taken from the same shipment as those used for the test mentioned in the polyethylene section that showed unusual hemorrhaging of the lungs. In both of these tests, the control rats were in good condition. However, this shipment possibly contained rats that were overly sensitive to certain gases.

Throughout our tests with polystyrene, there was no damage whatsoever to plants.

We have tested this material about as much as we have tested polyethylene. In general, our conclusions tend to run along about the same lines, i.e., it is basically a harmless material, it tends to soot, and high temperatures are needed in the burning zone. It is more configuration sensitive than polyethylene. We would rate this material as being slightly more hazardous than polyethylene in acute exposures.

Recipe Garbage. In order to compare plastics to other materials, we created a sort of "recipe" of garbage consisiting of various proportions of cereals, sawdust, rice or coffee. These recipes were fed into the same furnace used for burning plastic under essentially the same conditions.

All but two of the thirteen test-burns of this material were in the aerobic, continuously-fed mode. Only two tests were accomplished in the anaerobic mode, because of clogging of the auger. It seemed a bit ironic that plastics have the reputation for stoking difficulties; some combinations of these "natural" products were impossible to feed unless plastics were added. We did no batch tests.

There were three, six-hour plant exposures (aerobic mode). A total of 15 rats were exposed for six hours in the aerobic mode, and five rats were given six-hour exposures to effluents from the anaerobic mode. The final recipe used was 50% coffee grounds, 30% grape nuts and 20% hardwood sawdust. This is a Type II refuse mixture.

Any recipe was, in general, more difficult to burn than most plastics. Although the total flyash was greater, any damage to rats and plants for acute exposures was too slight to be detected. There were usually no hydrocarbon peaks greater than one part per million except when the fuel feed mechanism jammed or during a burnout of test material. There was quite a bit of carbon monoxide during periods of discontinuous flame.

Even during the poor burns, there was only a slight elevation in carboxy hemoglobin and a slight drop in the white blood count of the tested rats. In all cases, there was no damage to the plants.

These materials all contain more water than any of the tested plastics and are therefore temperature sensitive and quite likely to self-extinquish. However, when they reached temperatures where they were self-igniting, they became very difficult to feed in our mechanisms. They were at least as sticky as the plastics under these conditions.

Polypropylene. Polypropylene behaved very much like polyethylene in our furnace configuration. Temperatures in both furnaces ranged from 1400°F to 1850°F in these tests and combustion air ranged from about 83% to 157% theoretical air. This material appeared to have a higher air/fuel soot threshold (about 80% theoretical air as compared to about 70% for polyethylene). There was little or no difference in soot production between aerobic and anaerobic burns. This material was burned a total of six times in eight hour tests. Only one test used the "anaerobic" configuration. Two of the aerobic-burning tests included six hour exposures of plants. Only four rats were exposed for four hours during the anaerobic burn. Twelve rats were exposed for four hours each during aerobic burns.

The chemistry results depend upon the flame configurations, as with the other plastics. We normally found no hydrocarbon peaks greater than two parts per million. With low air/fuel ratios, the hydrocarbons increased and included methane, ethane and benzene and a C_7 compound, possibly toluene. In general, there was little or no carbon monoxide, ammonia, chlorine, etc.

During one test with 95% theoretical air, there was 91 ppm Cl^-, 56 ppm ammonia, a trace of cyanide, and about four parts per million nitrate-nitrite. This would seem to indicate that this compound included a small fraction of chlorines and acrylonitrile. This test had few observable effects on the rats. Though still within the normal range, the average of SGPT and SGOT were relatively low. However, the blood cross sections did not change. The necropsies revealed minor changes in the lung tissue - some hemorrhaging and color changes. However, the histological results were negative.

In all cases, even when burning under sub-optimum conditions, the plants were totally unaffected.

The overall conclusions that we have reached about polypropylene are similar to those of polyethylene and polystyrene. It usually burns cleanly and easily. It tends to soot more than polyethylene; it is configuration sensitive; but it is still a rather clean-burning material and apparently does not constitute an environmental hazard when burned at a high enough temperature with adequate premixing.

Phenol-formaldehyde. Two forms of this material were burned. One form was a compound used in bakelite switch plates - a wood-flour filled material. The other was a glue. Proximate analysis indicated about 40% ash for the glue and 14% ash for the other material. There were five full length tests with this material. A total of 22 rats were given 3 hour exposures. There were two,four-hour plant exposures.

The bakelite material gave relatively low flyash concentrations except when burned using underfire rather than crossfire air air. The glue had basically the same burning properties. Both were burned at about 1500°F in the primary furnace and 1750°F in the afterburner. Both types were slow-burning with a relatively low heat of combustion. Burning rates were quite erratic. The glue yielded low amounts of flyash; however, the flyash results were skewed strongly in the direction of the finer sizes. It yielded five to six times more of the very fine ash than did the wood-flour filled bakelite.

Chemical results indicated that both of these burned cleanly. There were only trace amounts of chloride (less than ten parts per million in all cases). There were always less than ten parts per million of ammoniacal nitrogen, less than one part per million cyanide and less than .55 ppm nitrate-nitrite. There were no detectable hydrocarbon peaks except methane and there was no detectable aldehyde-ketone.

The blood tests indicated no measurable hemoglobin changes. There were no physical difficulties evidenced by the rats. There were no unusual findings from the necropsies or from the histopathology. The plants were totally unaffected by the burning of this material.

Polycarbonate. We were unable to feed this material properly. Therefore, there are no chemical or toxicological data to report. This plastic seemed to melt more slowly than any other plastic tested. It seemed also slow to volatilize. When burned by itself, it left a refractory char. When burned as part of a mixture of plastics, that char was destroyed or else never formed.

We were able to keep it burning long enough once to obtain a particulate distribution measurement for the aerobic, continuously fed mode. It burned with less than average flyash production.

Barex 210.® There was only one, four-hour burn, including a two-hour exposure, on this plastic due to lack of material. It burned rapidly and cleanly. The toxicological results are very limited here. The five exposed rats were apparently unaffected. There were no blood changes. The necropsies and histology indicated nothing unusual. However, the next morning the leaves of the mustard and alfalfa had withered considerably and within a couple of days these plants were dead. The other plants were unaffected. Since we were operating just above 100% theoretical air on this test, this may indicate the presence of a nitrogen material - probably nitrogen oxides. We were not able to do a direct chemical analysis during the test because of lack of steady-state burning time.

Styrene-Acrylonitrile. We were able to test this material only once for eight hours, including a four-hour exposure. The combustion properties of this material were unusually good. The temperatures were 1800°F in both the afterburner and primary. The outstanding result of the test was that there was no measurable flyash except on the largest particulate plate, i.e., for those particles greater than 9.2 microns. The material, under these conditions, yielded four ppm NO, two ppm NO_2, about 2 ppm total aldehyde-ketone and 216 ppm HCl. There was no apparent damage to the eight exposed rats. The blood tests, urine tests, necropsies and histology all indicated no changes. The plants were totally unaffected by this material.

(As a point of emphasis, note that chemical measurements were made at the stack, before any dilution by cleaned air. The plants and animals received a diluted effluent, e.g., the plants were receiving about 30 ppm HCl during this exposure, not 216 ppm.)

Acrylonitrile - Butadiene - Styrene. This plastic burned four times in the aerobic, continuously fed mode using the second type of primary furnace, without the pneumatic feed. It behaved somewhat like polypropylene in the primary zone, in that it tended to give puffs of soot, even during generally clean burns. Apparently the stability of the flame was somewhat tenuous. This was a noticeable contrast to SAN where styrene was stabilized by a small portion of acrylonitrite.

The formulation of ABS used in these tests contained about 1% PVC. As a result, there was always some HCl present in the effluent, usually of the order of 200 ppm. On one inferior burn, we also found more than 16 ppm NH_4^+ along with 19 ppm CH_4. Any chloride was below our limit of detectability during this test.

Plants were exposed during all four tests (four-hour exposures) with no damage observed.

Twenty rats were exposed for four hours each, with no observable damage. The histology - pathology was negative.

Polyurethane. The forms of this plastic burned were rigid foam and rope. Both forms were fed via extruding wheels to the primary furnace. Because of limited material, only one brief test was run for each form. For the rigid foam, the test lasted only two hours. Both plants and the four exposed rats seemed totally unaffected. The test involving the rope was three hours long. The plants and six rats were exposed for 2-1/2 hours, again with no apparent or measured changes.

Urea-formaldehyde. This material was schizophrenic. When burned with adequate premixing and high enough afterburner temperature, it burned cleanly, like polyethylene. The high excess air required to stabilize the flame reduced the temperature of the primary furnace to about 1200°F. There were no hazardous effluents present. However, if there was not enough premixing or a high enough afterburner temperature, urea formaldehyde became the most hazardous and corrosive material encountered.

We spent more time on this resin than any other material tested. It was batch-burned many times; it was fed continuously in both aerobic and anaerobic modes. Several tests were made for afterburner temperature thresholds. Through all of this, we have not yet been able to isolate the principal toxins eluted during off-optimum burns. As of this writing, they may include ammonia, aldehydes (formaldehyde and acrolein), cyanides, and CO.

When this material was batch-burned, it was very hazardous. Plants were dehydrated irreversibly in just a few minutes. There were no obvious color changes immediately as there had been for PVC. The plants seemed to become slightly darker, wilt and die. The extent and overall rate of kill-off for land plants was about the same as seen for PVC. The rapidity of die-off, without color change, seems to indicate that the principal mode of attack was via a respiratory poison. Cyanide (and, therefore, the combination of NH_3 and CO also) is the most likely principal toxin [10, 42].

In batch burns, animals were more severly affected by this material than by PVC. Here the animals first showed irritation, then increased respiration rate, gasping, convulsions and finally death - all in less than five minutes. If the animals were removed prior to death, they quickly recovered.

The chemical analyses for batch burns of this material have been complicated by the presence of flyash [composed mostly of $(NH_4)_2CO_3$ and NH_4 HCO_3] and some soot. Significant components identified so far include methane, acetylene and ethylene, all in the 15 - 20 ppm range, HCN ranging from 2 to 30 ppm, and acrolein ranging from 3 to 10 ppm.

When burned in a premixed flame and high afterburner temperature (1700°F), this material completely changed character from the batch burns. Whether burned anaerobically or aerobically, in four-hour tests it caused no damage to the plants or rats. The chemical analysis showed about 2 ppm methane.

The flyash from urea-formaldehyde was hygroscopic.

If the afterburner was then turned off (after having first reached 1700°F) with the primary furnace still operating at about 1200°F, all remained well until it had cooled down to about 1400°F. As the afterburner temperature was lowered further, there was a sharp increase in the variety and concentration of trace gases. When the afterburner temperature reached about 1200°F, the plants and animals both showed symptoms similar to those seen in batch tests. The one difference was that the rats became slow and unresponsive before experiencing convulsions. The fumes were hazardous to the extent that we had to remove test animals about forty minutes after reaching 1200°F in order to expect any recovery. Even then, hemagology was difficult or impossible. We were able to obtain enough blood from the tail to measure only carboxyhemoglobin. This registered only about 15%. Recovery from these tests was relatively slow. Heart punctures did not yield enough blood to determine SGOT and SGPT. Necropsies revealed pale lungs, a darkened liver and pale brown kidneys in the exposed rats.

The histological examination of lung tissure from six exposed rats indicated a tendency toward acute bronchitis in rats exposed to effluents from sub-threshold (off-optimum) burning of urea-formaldehyde.

Melamine (Glue-resin). Only one, four-hour test was made on this material. The plants and four exposed rats seemed unaffected for most of the test. Toward the end of the test, the afterburner was turned off for ten minutes. As its temperature dropped below 1400°F (primary furnace @ 1450°F), the rats and plants reacted as they had to suboptimum burning of urea-formaldehyde. The rats became highly nervous with increased respiration rate, and then they suffered convulsions. The plants began to droop, while retaining their color. The next day they were dead.

The chemical analysis indicated that there were no measurable toxins until just after the afterburner went off, at which point cyanides and ammonium compounds appeared. This all happened so fast that we were unable to get a quantitative reading of these chemicals. We also did not have time later to repeat the test. (See Appendix XII, Test #7).

Polyvinyl Chloride. Hydrogen chloride was the principal toxin liberated during the burning of a mixture of PVC and cellulose products. In the absence of such a supportive fuel, PVC yielded HCl and CO along with traces of C_2H_4. The ethylene was observed only during sooting conditions. When tested in our apparatus, the HCl dominated corrosion and toxicological effects. However, there was a strong synergism observed for both corrosion and hazard when CO was present in significant amounts. We did not test for $COCl_2$. The rat and plant reactions seemed to indicate that toxic effects from $COCl_2$ were not dominant. The principal concern should therefore be with the HCl.

We burned this material without cellulose "dilution" ten times in the batch configuration. Each time we exposed plants and two rats. Two rats received three repeated exposures, and two rats received two repeated exposures. Each test was a disaster for the furnaces and transfer lines. We had grossly underestimated the low-temperature (130°F to 700°F) corrosion associated with the burning of pure PVC.

Both one week old and two week old plants were exposed to the effluent from three samples. One would expect the younger plants to be somewhat more senitive to pollutants. The difference in response, however, was astounding. The young plants died within one minute from the beginning of the exposure. By contrast, two-week old plants with the exception of mustard, were merely bleached and stunted, but not killed. On the basis of what we have observed with PVC and other materials, a good variety of very young plants may be and excellent and simple monitor of airborne pollutants, especially acids.

These brief exposures to PVC effluent produced immediate gross reactions in rats, also - increased respiration rate and irritation of the eyes. However, the rats survived and recovered. For about a week after their exposure, the rats acted sick. Their symptoms then disappeared and the rats appeared to be none the worse for their experience. After three months, the rats were necropsied and there was no apparent long-term damage. In fact, the rats that had been exposed appeared to be in good condition, especially at the lungs, which is significant considering their age. They were at least as healthy as the four control rats.

The residue from incinerated PVC affects the aquatic environment. The ash obtained from aerobic batch "burning" of polyvinyl chloride yielded leachates that were very toxic to fresh water algae and microscopic animals such as rotifers. Marine algae seemed to be unaffected.

Two aerobic, continuously-fed tests using the air-auger feed were made using pure PVC. Both tests lasted five hours, with four-hour exposures to plants and a total of eight rats. The combustion air for the first was 300% theoretical air and 620% theoretical air for the second. Because of the low heat value of the PVC and the high air/fuel ratio needed to sustain continuous burning, the afterburner temperatures were about 600°F lower than set point in spite of normal power input. This partially accounts for some of the high CO readings (note HbCO values). In contrast to the batch burns in which a large volume of char-residue remained, there was no residue left from the continuously-fed tests.

For the chemical analysis, the effluent was first bubbled through a 0.1 normal NaOH bath to remove HCl. After the trap, there were no trace hydrocarbons measurable by F.I.D, except for methane in quantities less than 2 ppm. The bath was also checked by extraction and GC; there were no hydrocarbons observed. However, this whole analysis should be repeated using a different trap configuration, because it is likely that trace hydrocarbons were "lost" to reactions in the trap and its extraction. Our electron capture detector and its oven had been damaged just prior to these tests, and so it was not available for use.

The reactions by the plants and animals were severe, as expected. In four-hours the plants were quite dead, and the animals showed severe gross reactions, more severe for the higher theoretical air, even though the dilution ratio was the same. The blood analyses revealed an increase in HbCO and a sharp decrease in white-blood-count. The gross reactions were as follows. (A) The eyes were swollen shut, accompanied by a bloody discharge from that area.

(B) There was sometimes a white film covering the cornea. (C) The nose was reddened and often a bloody discharge occurred here also. (D) Usually a gray, mucous-like, discharge eventually covered much of the rat's ventral surface. This was possibly encouraged by the rat's incessant washing in reaction to irritation. (E) There was extensive burning of the feet, sometimes accompanied by edema and blistering. These gross symptoms all disappeared within about 24 hours, except for a few burn lesions on the face and feet that were healing.

The necropsies taken about 24 hours after the end of exposure indicated enlargement of the lungs with some hemorrhaging. The lymph follicles were raised through the gastro-intestrinal tract; near the entrance to the cecum, the ileum was filled with blood, mucous and gas. There was extensive dilitation of the renal pelvis of the kidney.

There is one unusual result regarding corrosion to be noted from these tests. All points of the system were kept above 50°C to prevent condensation of water. From this temperature on up to the highest temperature available to the effluents (1900°F at the surface of the primary furnace elements), the short-term damage of metallic components decreased with increasing temperature. This contradicts experience with municipal units [26, 30] where slag components and SO_2 are present. It is possible that CO, in the absence of slag or SO_2, is tying up high energy surface locations. This would mean that chemisorbed CO on metallic surfaces is an inhibitor to dissociative chemisorption on that surface [43], e.g., HCl on ferrous metals. Higher temperatures make more metal available to the competing gases by increasing migration; the competition would tend to favor CO. The overall rate of HCl corrosion in this case would be limited by CO until the latter begins desorption at high temperature.

Because of the importance of Cl^- in incineration corrosion, we digressed for a corrosion test involving 50% PVC and 50% mustard seeds, holding all other parameters the same. The seeds acted basically as an auxilliary fuel. This particular fuel was chosen strictly for ease of metering through the pneumatic feed. The mixture burned at 150% theoretical air with a consistent flame and no detectable CO. The degree of metal wastage was sharply increased. More important, the highest temperature surfaces were now the hardest hit. Only about one tenth the HCl reached the exposure chambers, the remainder being lost by reaction in the primary furnace, in the ash-residue, and to the flyash. We conclude from this that in the absence of slag or SO_2 there exists a corrosion synergism between CO and HCl.

Because of the reduced HCl reaching the chambers and lack of CO, the rat response to this last test was much milder than in previous exposures. The reactions were still quite severe with sharp drops in W.B.C. and extensive lung damage. All eight rats survived the four-hour exposure. In spite of the reduced HCl present, the plants were wilted in a half-hour and were dead by the end of the exposure.

The flyash from all three tests was about 96% volatile in the absence of air. In the presence of air it was quite refractory.

The results of our tests do not represent new findings. PVC has a well-deserved, bad reputation in incinerators. The only surprise to us was the severity of the attack of this material's effluents on metals and plants. We were prepared for problems due to the rich HCl effluent, but not of the order of magnitude presented by the incineration of this material.

The ease with which the Cl^- leaves the PVC matrix is the basis for possible solutions to the corrosion problem. We recommend that this material be subjected to pretreatment at about 300°C before introduction to an incinerator. The development of a two-step process such as this is a possible alternative to preferential taxing or outright bans of a very useful material. Please see No. 1 in the section entitled "Recommendations."

Plastic mixtures. Three tests were completed using various plastics mixtures in several furnace configurations. In the first test, the pit incinerator model was used with a pure plastics mixture - there was no dilution of the plastics by cellulose. In the second test, this same mixture was fed through the first design of the primary furnace using the air auger feed. The third test involved feeding forty percent plastics mixture with sixty percent mustard seeds to provide a cellulose dilution. In each test, plants and six rats were exposed with four control rats in each test. The exposures lasted for four hours. The first test with the box burner was not very successful in that there was a great deal of carbon monoxide and soot given off in this configuration. The plants were three weeks old in contrast to the usual one or two week old plants. These wilted during the test but semed to come back fairly well when placed in the greenhouse after the test. The second test, using the air auger feed and the usual primary furnace, was much harsher on the plants. In this test, we had one-week old and four-week old plants both of which failed to survive. During the third (and last) test, in which the plastic mixture was diluted by cellulose, approximately one-half of the one-week old plants died. The most sensitive plant to polyvinyl chloride throughout our tests has been mustard and that was the first to wilt and die. The alfalfa likewise died during the test. The oats and beans both suffered damage to their leaves but other wise survived the exposure. Approximately one-half of the squash plants survived and the Kentucky bluegrass, though stunted, also survived. The rats for all three tests experienced increased HbCO in spite of the fact that we were burning with about 300% theoretical air. The increases were most severe for the first test. The necropsies and general physical observations indicated that the dominant toxin was probably HCl. Polyvinyl chloride was present as twenty percent of the first two mixtures and eight percent of the last mixture.

The combustion properties of the plastic mixtures were in general superior to those of the individual burns. The ignition was simple and steady, and the maintenance of a good flame was simpler. The attainment of the relatively high temperature (1750°F) in the primary furnace was quite easy.

The chemistry indicated a fair amount of chloride present although much of the chloride was apparently absorbed by the furnace and by the soot. There was no detectable aldehyde, nitrogen oxides, ammonium ions, or cyanide. No gas chromotagraph data was taken for these tests. The ash residue from the last test contained approximately 4.5 percent (by weight) ionic chloride. There is a possibility of additional organic chlorides being present as well, although these were not checked.

The composition of the plastics mixture was based on the percentages of plastics manufactured in 1970. The composition is given in the appendix.

CONCLUSIONS AND DISCUSSION

1. The principle conclusion of this work is that, on a tonnage of production basis, most of the resin used in the formulation of plastics can be burned readily, cleanly and safely. The tests whose results we have just presented are relatively severe tests, in that pure resins were used generally without dilution by cellulose or other "natural" materials. Usually in municipal refuse plastics will show up as minor constituents of the order of 1% to 10%. Thus their environmental importance would be expected to be less than what we have measured here.

2. There seemed to be three classes of materials within the set of tested resins. The first class consisted of hydrocarbons such as polyethylene, polystyrene, and polypropylene; possibly polycarbonate can be included in this class as well. This class seemed to be potentially less hazardous than the other two classes of materials. The second class of materials consisted of those that contained nitrogen, such as polyurethane, ureaformaldehyde and melamine. These materials when burned under optimal conditions behaved quite nicely. However, if consumed in off-optimum combustion, i.e., something like open burning, they gave off toxins such as cyanide, ammonia and aldehydes, most of which are more hazardous than carbon monoxide. The third category would seem to consist of the halogenated materials, of which we have tested only one. Our sample of one, PVC, yielded hazardous effluents no matter how burned.

3. It was our intent to avoid filled materials as much as possible and to deal with as pure a resin as possible in order to obtain a starting point for subsequent research in the behavior of plastics. However, all of the materials used here were commercially available polymers, and as such contained trace quantities of various metals, for instance, octal tin. None of our measurements detected influences of these trace materials.

4. In many of these tests the flame-fuel interface exhibited a strong sensitivity to the air/fuel ratio. It should be emphasized that it is the air/fuel ratio near that interface that will determine the toxicological character of the gas leaving the primary furnace rather than the overall air/fuel ratio of the incinerator. For instance, note the ureaformaldehyde or polyurethane tests in which there were high overall air/fuel ratios, even during off-optimum burning. These high combustion air values were created partially by the high excess air injected downstream of the primary furnace to boost turbulence in the afterburner. The interface between the fuel and the air was still experiencing something on the order of 150% theoretical air during good burns.

5. Since the degree of cleanup in the afterburner is dependent on the aerodynamics in that afterburner, it is useful to look at a simple parameter describing those aerodynamics, namely the Reynolds number. Typically the gases traveling up the afterburner had a velocity on the order of five feet per second. This yields a Reynolds number, depending on the temperature of the afterburner, in the range 1000 to 2000

for a three-inch diameter tube. If we believe the Langhaar equation [44]

$$\frac{L}{D} \approx 0.06 \text{ Re}$$

where L is the developmental length for fully developed flow, we will need approximately 20 feet for aerodynamic development of flow in the 3 " tube. Since the tube was only three feet long, it is quite safe to assume that we had essentially undeveloped flow. It follows that the placement of the intakes for chemical analysis or for transfer lines to exposure chambers is not particularly critical. This also means we have a simplified diffusion relationship to work with for transfer of oxidized species from the wall to the interior of the tube. Because of this and because of the turbulence in the tube it is safe to assume that the animals were receiving a representative sample of exhaust, and that our chemical probes were measuring a representative sample for the entire cross section of the tube even though they were placed in the center only. This will lead to some error; there will be fewer oxidized species near the center than at the edge of the tube. However, the error in that measurement should not be very large.

6. For some of the ash residues, especially those associated with the mixture tests, proximate analyses done according to ASTM methodology yielded more than 100% totals. For instance in one residue the percentage of water and volatile matter was measured to be 85%, and the total ash content was measured to be 55%. Since we all believe in

the conservation of matter, it must be that some of the compounds present in the residue are conjugated in such a way that when heated in the absence of air they will volatilize, but when heated in the presence of air they neither volatilize nor burn. It would be useful in any subsequent studies of the incineration of plastics to pursue the effects of these conjugated compounds.

7. One of the original goals of this research was to compare the two-step homogeneous burning to the one-step heterogeneous burning for effectiveness in eliminating toxins. The results as already stated seem to indicate that there are few advantages in using the two-step (anaerobic) mode for plastics. Polyethylene and polypropolene both burned somewhat better in a two-step combustion process; however, any of the materials containing styrene and a number of the nitrogenous materials burned less well in the two-step process. It may be that once scaled up to pilot plant or commercial size this would no longer be true; the success of the Torrax process is indicative of the advantages of the two-step combustion format. However, our tests here did not indicate many advantages of that method over the one-step heterogeneous burn with proper air configurations and proper afterburning.

8. The use of a single plastic in a simple flame configuration or at least with simple flame constraints yields an additional difficulty that we had not counted on - a great variation in the measured relative toxicological potential of the material. The near-optimum burns were likely to vary chemical results by factors of two or three

or four, with *all* the results still within what could be called a "safe" range. A more severe problem was that only a change of inlet-air pipe orientation relative to the fuel bed by 5° was needed to go from optimum to off-optimum with some materials under certain constraints. Thus while trying to achieve a clean flame we ran the risk of ending up with a variety of flame configurations. Sometimes the geometry of the furnace and geometry of the air inlet cooperated to give us a bi-stable, tri-stable or quad-stable burning configuration; we could, therefore, find two, three or four toxicological maps for the same plastic, with the same air/fuel ratio, in the same furnace under the same apparent constraints.

A flame is almost by definition, unstable, because it is an unstable chemical response to aerodynamic constraints. Of practical importance is that we could not characterize the flame completely in some instances. The flame would sometimes be attached to a cool surface, then migrate to a warmer surface and then stabilize in a turbulent, homogeneous unattached mode, and then attach to the original surface; all of this during the same test.

We did not consider this a disadvantage, for it exposed the rats and plants to a variety of conditions, all of which were fairly good; it yielded effluents, flyash and chemical readings that were more representative of averages, since readings were normally taken over periods ranging from a half an hour to two hours. By this averaging that occurred quite by accident, we accomplished results that may look a little more like a larger incinerator, where the performance is the result of an average of the very many different types of flames in a given fuel bed. It follows that the quantitative results presented here should not be endowed with a great deal of expected reproducibility. On the other hand, these results give a good estimate of what to expect chemically and toxicologically when burning these materials in non-laboratory situations.

9. As mentioned before, the N- containing plastics yielded surprisingly small quantities of NO_x. Moreover, as the combustion conditions improved, i.e., as the combustion temperature and completeness of combustion increased, the fraction of NO_x decreased. Depending on the nitrogenous plastic being consumed, $(NH_4)_2CO_3$ or NH_4HCO_3 were given off in addition to CN^-, aldehydes, CO, and nitrite-nitrate. Our equipment and procedures were not set up to measure N_2O, although Boettner [45] has tentatively measured N_2O while pyrolyzing polyurethane in air.

We have postulated the following three-step outline for the mechanism of destruction of CN^-, N_2O and NH_3 without generation of NO_2 in complete reactions with oxygen below 2000°F. (1) Ammonium compounds, CO_2, simple amides, N_2O, formaldehyde or acrolein, water and hydrogen cyanide are created during the pyrolysis step. Hydrazine may also form during this step if compounds like urea are being burned in enough O_2. Nitrous oxide is formed at the surface in the presence of sufficient oxygen, and it is the principal oxidant in the third step. (2) The rate-limiting step is the reaction of NH_3 with CO to form HCN.

If sufficient oxygen is present, any hydrazine will be oxidized quickly to N_2O and water during this step. (3) The amides and hydrogen cyanide are quickly oxidized by N_2O. The products of these reactions are likely to be N_2, CO, CO_2 and H_2O [46].

10. We have attempted in this study to combine elements of chemical analysis, combustion theory and phenomenology and rather rudimentary toxicology (which we have chosen to call biomonitoring) in order to evaluate a set of materials. It may be frustrating to the reader who is a specialist in some of these disciplines to read this report, because we have deliberately taken pains to be nonacademic in our approach to this problem. For instance, instead of dealing with nice, polite, laminar flat flames or candlelike flames, both of which are easier to reproduce, neither of which are usually found in an incinerator, we have attempted to operate with flame configurations that approach those found in incinerators. Furthermore, when trying to combine three areas of research each discipline has to compromise in order to partially fit the other's framework.

11. The effluent gases were exposed to a limited set of materials. We designed our apparatus so that the plastic and its effluent encountered only stainless steel and materials that were dominated by silica or alumina. The afterburner tubes were constructed of Alundum® which was 11% silica and 89% alumina, and during chemical analysis, the gases were exposed primarily to glass, stainless steel, and column packings. On the face of it this seems to be a very pure type of

arrangement. However, by being exposed just to glass, the gases were exposed to a variety of materials, e.g., sodium carbonate, sodium bicarbonate, traces of zinc, etc.; when exposed to stainless steel, these gases were being exposed to nickel oxides, chromium oxides, iron chlorides, etc. Also there was always the inevitable carbon deposits to which these effluent gases were exposed. This variety of solid surfaces reduces the predictability of chemical reactions during measurements.

12. The gas chromotagraph was a disappointing tool for this work. In our original request we had asked for a mass spectrometer because of the necessity of doing rapid, on-line analysis. The review committee decided that we should use gas chromatographs instead. We did, and our research was slowed considerably because of lack of rapid on-line capability. The present state-of-the-art in incineration indicates little need to examine furnace effluents for anything other than the major gases such as HCl from PVC and carbon monoxide from off-optimum burning of any combustible. The fancy chemistry should be left for analyses of the residue and flyash. Combustion conditions could be monitored most easily by knowing the carbon monoxide, the aldehydes, particulate distributions, and possibly NO_x. The protocol developed by Carotti [Ref. 29] seems quite adequate. Perhaps an adequate method would be simply to take the entire effluent, pass it through 400°C nickel filings in the presence of hydrogen to convert the carbon monoxide to CH_4

while leaving the other hydrocarbons intact, and then pass the entire mixture to a flame ionization detector using it as a total hydrocarbon device. If off-optimum burning were to be emphasized it may be useful to add a total organic nitrogen detector. In short, our chemical apparatus and analyses were more complicated instrumentally than they had to be. As a result we lost much time.

13. The pre-test data was used in two ways - to determine shifts in body chemistry and to eliminate "unhealthy" rats from the test. If pre-test values were abnormal, the rat was not used. This helped to insure against synergism between pathogenic effects and the effects caused by the burning plastic's effluent. However, this screening process may have skewed the results in that we were examining only "normal" rats, not average ones. Therefore, we obtained little or no information about effects on weaker rats.

Besides giving direct information about damage to internal tissues by exposure to the effluent, necropsies also served as part of the "selection" process. When necropsies indicated that a significant portion of a shipment of rats was diseased, those tests planned to involve the remaining rats from that shipment were temporarily suspended, until a new shipment could be obtained.

14. One of the criticisms of this work has been that we have been using unadulterated plastics rather than diluting them to the percentages that would appear in municipal refuse. This is a philosophically valid but experimentally useless objection. In the first place there

is no guarantee that plastics will always be diluted, especially for on-site, industrial incineration. The data gathered here will be of direct use to industries who may have to burn one or more of these resins at 100% strength. Secondly, the toxicological hazard associated with 100% strength gives maximum insult to the animal and is consistent with other toxicological methods. For instance, in pharmaceutical drug testing for side effects, exposures are typically 50 to 100 times the anticipated recommended dosage. The same philosophy was applied to this set of tests. If a given plastic can be burned with apparent safety at 100% strength, then it should be easier to trust this material's environmental impact when it is only a few percent of a waste stream.

Thirdly, if dilution of the tested material is requested as a prerequisite for "reality", we must ask, "What will you use for dilution of the tested material?" Chemical and toxicological results of the mixture are not likely to be subject to linear superposition of results obtained from constituents of that mixture. Therefore, the material used to dilute the material being tested could significantly alter the results of the test. On the other hand, if no superposition is granted, then all bets are off. Materials testing would be a waste of time. If some degree of superposition is granted, we will need to know the chemical and toxicological behavior of the constituents of the mixture, each constituent burned at 100% strength. The results reported here, therefore, should help provide a basis for predicting the environmental impact of the tested resins as parts of various mixtures.

RECOMMENDATIONS

1. By comparison to other materials tested, PVC was very hazardous and corrosive. There is no doubt but that PVC can be incinerated safely; so can strontium 90 and selenium. However, the presence of even trace amounts of various "difficult" materials, significantly increases the cost of disposal of the total accompanying materials. PVC may only comprise about 0.3% of the waste [29] but it certainly creates much more incinerator corrosion or costs and environmental damage than its 0.3% entitles it to create. Since the HCL so readily leaves the material at about 300°C, pretreatment for removal of the Cl^- should be inexpensive relative to the costs of repairing damaged incinerators.

The EPA in conjunction with the Society of Plastics Industries should undertake development of pretreatment processes for removal of Cl^- prior to the introduction of chlorinated plastics to an incinerator. This pretreatment may resemble the Takuma process [25].

During our three years of research we found ourselves pleasantly surprised by every *material* tested, in terms of effluent chemistry, toxicology, and relative ease of burning, except PVC. During this three-year period we also witnessed the development of an impressive effort by the Society of Plastics Industries to defend the disposability of PVC. It seems to us that the SPI has little to lose by admitting they represent the producers of a very useful material called PVC, which also happens to create solvable difficulties in incinerators.

The best interests of SPI and EPA would probably be served if SPI would convert their "PVC Defense Fund" into a "Safe Disposal Fund", with a little augmentation from EPA.

2. Certainly PVC is not the only corrosive agent entering incinerators. There are other sources of HCl, as well as SO_2 and slagging metals. A pretreatment step similar to the Takuma Process should take out most of the acid gases, and separating combustibles from noncombustibles should eliminate most of the slagging sources.

We would therefore recommend the following scheme for incinerating solid wastes:

A. First, shred the waste, with ballistic sorting.

B. The combustible material would then be preheated to 300°C. The water vapor, HCl, SO_2, and other fumes given off would pass through a lime or limestone bed before entering the main incinerator.

C. The remaining combustibles would then be introduced to the incinerator.

3. The literature indicates that not too much of the toxicological fire hazard work has been done with a flame present. Much of the work has involved smoldering materials. One of the principal conclusions to date has been that carbon monoxide outweighs all the other toxins in its potential as a hazardous material given off during the quasi-combustion of home materials. However, if a flame is present, the carbon monoxide may not be the dominant problem with many materials. Other simple toxins such as hydrogen cyanide may dominate.

Because of the difficulties encountered in off-optimum burning of nitrogenous compounds, particularly ureaformaldehyde, urea, and melamine, all of which are used in glues, we recommend that fire hazard studies be initiated on these materials. If there is deficient air these may be as serious a toxicological problem as polyvinyl chloride, especially with the increased use of acrylon rugs, wood paneiling and such.

4. The toxins we identified are compounds likely to be emitted from sources other than incinerators, e.g., much HCl comes from fossil fuel consumption. Therefore, separate biomonitoring of gaseous incinerator effluents is of limited usefulness for urban areas. On the other hand, leachates from incinerator residue dumps are likely to be different, qualitatively and quantitatively, from other stream pollutants. Therefore, biomonitoring techniques should be developed for aquatic plants and animals. We had originally intended to do this but time did not permit it, except for the one preliminary test on PVC char.

5. The polyurethane and melamine tests that were conducted here were conducted at the very end of the contract period. We do not feel that these have been tested as much as they should in a configuration similar to ours. We therefore recommend that these tests be extended in more detail.

6. Even though some of these materials appear to be without hazard when burned by themselves or burned in the presence of other plastics, it is conceivable that there are combinations of these plastics and their fillers that are more hazardous than what we have observed here. In particular, inert fillers that are used in some plastics may be

effective carriers of toxins to the lungs. When filler sizes are less than three microns, they will be able to penetrate to the inner lung regions, carrying with them whatever gases are adsorbed on their surface. Even the larger fillers, which will be trapped further up in the respiratory system, are capable of producing allergic or other unfavorable reactions. It would seem useful to study the influence of fillers on the toxicological, chemical and combustion behavior of various resins. Our feeling is that fillers whose dimensions are less than 3 microns should be kept out of plastics. All that would be required is a simple meshing to remove the ultra-fine fillers for use in some other aggregate. Of particular note here is the calcium carbonate that is used in the rigid polyvinyl chloride applications. This filler is useful for tying up the hydrogen chloride, but quite often it is in the submicron range of sizes [47]. Another example is rutile in polyethylene.

7. It was our general feeling that the rat exposures, and even some of the plant exposures were not useful. It would seem that unless chronic tests are to be done, the biomonitoring system should include a variety of phyla rather than a detailed study of just a few species.

It is at least difficult to predict human response on the basis of test of animal or plant response. This is a problem when working either with just one species or with a variety of species. The advantage, however, of working with a greater variety of species is that the likelihood of hitting a weak spot in the environment is greater. There are many pollution situations that endanger man directly or indirectly through his food chains. It is possible that such danger may not be seen through a detailed study of just a few species. Rats for instance tend to be more resistant to certain toxins than are humans. If a larger number of phyla can be observed, then we stand a higher probability of knowing that something is wrong. However, it may now be more difficult to find what toxins are present, or if they are appearing in concentrations hazardous to humans. It certainly would not be a simpler mode of biomonitoring or of toxicology, but our feeling is that it would be a more complete one. The difficulties of interpretation are increased by working with a greater number of phyla. But that is perhaps more bearable than the difficulties of observation created by limiting ourselves to just a few species.

8. Any subsequent work on rats should involve the use of larger numbers per test, of exposed animals in each species, as well as larger numbers in the control groups. If these numbers were large enough, the pre-test selection processes would not be necessary. One consequence would be that weaker rats would be tested as well as the "normal" rats used in this work.

9. Chronic studies are very much in order as a next step. It would seem useful to expose rats, land plants and some aquatic species for their entire life cycle. Other chronic tests should be devised to examine long-term damage including carcinogenic effects, from the effluents of nitrogenous materials and possibly polystyrene. In conjunction

with these chronic studies, histo-pathological studies of nervous tissue would be helpful.

It may be useful to give the same animals and plants repeated, chronic exposures, e.g., eight-hour exposure, 16 hour purge cycles for several days or weeks.

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APPENDIX I

Description of Appendices : Format and Normal Ranges.

With the exception of the first and last appendices, each appendix is devoted to a single material or to a particular, defined mixture. The first page of each appendix describes the material tested. Following this are the details of the constraints and results of representative tests on that plastic. Some test results contain furnace data, effluent chemistry, and toxicological data. Some tests were "incomplete," in that for some reason, usually instrument failure, the entire set of test parameters were not measureable. In most cases this information for the plastic is indirectly available through the results of one of the other tests.

The average and standard deviation of measured values for the blood testing parameters were computed for sets of untested rats. The "normal" sample consisted of 150 randomly chosen pre-test values and/or control rat values for hematology and urinalysis parameters, and 50 randomly selected control rats for SGOT and SGPT. The results are listed on the next page.

NORMALS

Parameter	Average and Standard Deviation	
Hemoglobin	16.6 ± 1.1 (gms/100mℓ)	
Carboxyhemoglobin	0.5 ± 0.5 (% Hb)	
Hematocrit	49.4 ± 3.2 (% of packed red cells)	
Mean Compuscular Hemoglobin Comentration (MCHC)	33.7 ± 2.0 (gms/100 mℓ)	
Total Leukocyte Count (W.B.C.)	15,200 ± 3400 (cells/(mm)^3)	
SGOT	107 ± 43 (units/mℓ)	
SGPT	30 ± 11 (units/mℓ)	
Qualitative Urinalysis		
Volume	21 ± 6 (mℓ)	
Specific Gravity	1.02 ± 0.1	
pH	6.5 ± 0.5	
Protein	0 - 30 (mg/100 mℓ)	ACCEPTED RANGES
Sugar	0 (mg/ 100 mℓ)	
Ketone	0 (mg/ 100 mℓ)	
Bilirubin	0 (mg/ 100 mℓ)	
RBC	0 (Average number/HPF)	
WBC	0 - 5 (Average number/HPF)	
Epithelial/cells	0 - 5 (Average number/HPF)	
Casts	0 (Average number/HPF)	

APPENDIX II

Polyethylene

1. Form. Low density PE beads. Courtesy of Union Carbide.

2. Proximate Analysis. 99% volatile matter. 1% moisture.

3. Nature of residue. None ever present.

4. C, H, N Analysis. C - 86%

H - 14%

N - 0%

5. Air/fuel values at 100% theoretical air.

$$\frac{\text{Moles of air}}{\text{mole of PE}} = 14.3$$

$$\frac{\text{ft}^3\text{ of air}}{\text{gm of PE}} = 0.431$$

at p = 76 cm of Hg

T = 20°C

Tests 1, 2, and 3. Batch burning. Crucible with 25 gms of PE inserted in afterburner tube, about 12" from bottom of tube for each test.

There was no visible flame for three minutes; during which time much CH_4, C_2H_4 and other hydrocarbons were given off, along with much soot. Each time there was visible flame for approximately six minutes. No residue was left in the crucible. Afterburner temperature was preset at 1300°F, and peak temperature near crucible was 600°F above its ambient. The turbulent, candle-like flame was attached to the crucible. The air/fuel ratio was not determined.

Quantitative chemical analyses were made three minutes after ignition. Average of three tests :

CH_4	20 ppm
C_2H_4	8 ppm
C_2H_6	5 ppm
Other hydrocarbons	12 ppm

The exposed one and two week old plants were unaffected. The two exposed rats indicated no gross symptoms. When necropsied four months later, they appeared to be no worse or better than the two control rats. The dilution ratio of clean air to effluent was about 4 : 1.

Test 4

Constraints

Continuously-fed, aerobic with auger feed.

Combustion air introduced at bottom of primary furnace rather than blowing directly across fuel.

Primary Furnace Temperature. 1700°F ± 50°F

Afterburner Temperature. 1800°F ± 50°F

Air/Fuel Ratio. 120% T.A.

Fuel Consumption Rate. 120 gms/hour

Length of test. One-hour burning time.
One-hour exposure time.

Combustion Properties

Flame. No apparent attachment location.
Not a very consistent flame. Quite turbulent.

Flyash. Total. 61 mg/hour or
0.52 mg flyash/gm fuel

Test 4.

Flyash Distribution

Plate		mg/gm
1	(>9.2μ)	0.014
2		0.043
3		0.064
4		0.081
5		0.099
6		0.109
7	(<0.3μ)	0.108

Chemical Results. None

Biomonitoring Results. (Dilution ratio; air: effluent = 6.)

Plants unaffected.

Rats not tested.

Test 5.

Constraints

Continuously-fed aerobic with auger feed. Combustion air introduced directly across fuel as in Fig. I

Primary Furnace Temperature.	1650°F ± 50°F
Afterburner Temperature.	2000°F ± 50°F
Air/Fuel Ratio.	125% T.A.
Fuel Consumption Rate.	115 gms/hour
Length of Test.	Four-hour burning time. Four-hour exposure time.

Combustion Results

Flame. Attached to auger guide throughout test. Turbulent. Good premixing. Hot flame. Always ignited.

Flyash. Not measured.

Test 5.

Chemical Results

Methane	0.5 ppm	
Ethylene	0.88	
Ethane	0.40	
Acetaldehyde	2.00	Tentative Identification
1,3 Butadiene	2.30	
Cis 2 - Butene	0.25	
n - Butene	0.25	
2,4 Dimethylpentane	6.60	
CO	<15 ppm	

Biomonitoring Results (Dilution ratio; air: effluent = 6.)

Plants unaffected.

Rats not tested.

Test 6.

Constraints. Same as for test #5, but only a two-hour burn; no exposures.

Combustion Results. Same as for test #5, except that flyash was now measured.

Flyash. Total. 12.2 mg/hour or 0.104 mg flyash/gm fuel

Distribution

Plate		mg/gm
1	(>9.2μ)	0.025
2		0.019
3		0.013
4		0.013
5		0.022
6		0.005
7	(<0.3μ)	0.008

No Chemical or Biomonitoring Results.

Test 7.

Constraints. Continuously-fed aerobic with auger feed. Combustion air introduced as in Fig. I (crossfire air).

Primary Furnace Temperature.	1500°F
Afterburner Temperature.	1900°F
Air/Fuel Ratio.	150% T.A.
Fuel Consumption rate.	120 gms/hour
Length of test.	Five hours burning time

Combustion Results.

Flame. Same as test #5.

Flyash. Total 0.202 mg flyash/gm fuel

Distribution

Plate		mg/gm
1	(>9.2μ)	0.0042
2		0.0158
3		0.0167
4		0.0233
5		0.0375
6		0.0430
7	(<0.3μ)	0.0610

No Chemical or Biomonitoring Results.

Test 8.

Constraints. Continuously-fed aerobic with auger. Crossfire air.

Primary Furnace Temperature.	1550°F
Afterburner Temperature.	1620°F
Air/Fuel Ratio.	150% T.A.
Fuel Consumption rate.	120 gms/hour
Length of test.	Eight hours burning time. Six hours exposure time.

Combustion Results.

Flame. Attached flame. Consistent, good ignition.

Little turbulence.

Flyash. Total. 0.056 mg flyash/gm fuel.

Distribution

Plate		mg/gm
1	(>9.2μ)	0.00092
2		0.00216
3		0.00730
4		0.0102
5		0.0135
6		0.0127
7	(<0.3μ)	0.00975

Test 8.

Comments. 1. No chemical results.

2. No plant tests.

3. Only gross observations of rats. Apparently not affected. Dilution ratio - only four parts clean air to one part effluent. Some condensation at inlet to exposure chamber.

Test 9.

Constraints. Continuously-fed, aerobic, auger, crossfire.

Primary Furnace Temperature.	1600°F
Afterburner Temperature.	1750°F
Air/Fuel Ratio.	145% T.A. (indicated)
Fuel Consumption rate.	120 gms/hour
Length of test.	Seven hours burning time. Five hours exposure time.

During this test the air reaching the primary chamber decreased to an unknown value due to a leak in the air line between the meter and the furnace. Estimate A/F ≈ 75% for four hours of the exposure.

Combustion Results. There were no feeding difficulties, and the flame appeared to be about the same as that observed during test #8. Flyash was not measured; however, no visible flyash.

Chemical Results. One percent carbon monoxide. (very high)

Biomonitoring Results. (Dilution ratio; air: effluent = 7).

Plants. Some test plants slightly wilted (beans and mustard). Edges of some of the two-week-old mustard plants yellowed. Control plants excellent. One week later, all symptoms had disappeared, except mustard still had a few yellowed leaves.

Rats. None tested.

Test 10.

Constraints. Anaerobic, continuously-fed (auger), air fired across tube, but not across fuel.

Primary Furnace Temperature.	1520°F
Afterburner Temperature.	1800°F
Air/Fuel Ratio.	94% to 105% T.A.
Fuel Consumption rate.	196 gms/hour.
Length of test.	Six hours burning time. Six hours exposure time.

Combustion Results.

Flame. Continuous ignition. No apparent attachment point. Very good flame.

Flyash. Total, 0.076 mg flyash/gm fuel.

Distribution

Plate		mg/gm
1	(>9.2μ)	0.0082
2		0.0214
3		0.0122
4		0.0153
5		0.0092
6		0.0056
7	(<0.3μ)	0.0036

Test 10.

Chemical Results. Carbon monoxide output ranged from ten to thirty ppm.

Biomonitoring Results. (Dilution ratio; air to effluent = 7.)

Plants. All plants apparently unaffected.

Rats. Not tested.

Test 11.

Constraints. Same as test #10.

Primary Furnace Temperature.	1500°F
Afterburner Temperature.	1800°F
Air/Fuel Ratio.	182% T.A.
Fuel Consumption rate.	96 gms/hour.
Length of test.	Six hours burning time. Four hours exposure time.

Combustion Results.

Flame. Very good flame. Continuous ignition. No apparent attachment point.

Flyash. Total, 0.121 mg flyash/gm fuel.

Distribution

Plate		mg/gm
1	(>9.2μ)	0.030
2		0.020
3		0.020
4		0.018
5		0.014
6		0.009
7	(<0.3μ)	0.010

Test 11.

The appearance of this flame was unchanged from the previous test, in spite of halving the fuel rate, while leaving the combustion air flows unchanged.

Chemical Results.

Chemical	Mole fraction (ppm)
CO	4
CH_4	7

All other gases below our limits of detectability.

Biomonitoring Results. (Dilution ratio; air: effluent = 6.)

Plants. None tested.

Rats.

Number of control rats.	One
Number of exposed rats.	Five
Length of exposure.	Four hours

Blood Work

Function	Hb(g/100 ml)	% CO	W.B.C.	Hematocrit	MCHC
Pre test	17.5 ± 0.2	0	14,400 ± 2000	48 ± 1.8	36.6 ± 1.3
Test	15.2 ± 0.3	1.8 ± 1.1	15,900 ± 2100	42.2 ± 0.7	36.3 ± 0.4
Control(1)	15.0	0	16,700	41	36.5

Necropsy Findings. None

Comments. 1. In the blood work the pretest values always include the control rat. The "Control" values are determined after the test.

2. No SGOT, SGPT or urine determinations made for this test.

Test 12.

Constraints. Continuously-fed, auger, crossfire, aerobic mode. After two hours of burning the afterburner heating element failed and afterburner temperature dropped quickly to 1100°F.

Primary Furnace Temperature.	1550°F throughout.
Afterburner Temperature.	1600°F for first two hours, ~1100°F during last four hours.
Air/Fuel Ratio.	125% T.A.
Fuel Consumption rate.	~150 gms/hour.
Length of test.	Seven hours burning time total. Three hours total exposure time. Rat exposures were started one hour before element failure.

Combustion Results.

Flame. The primary furnace flame was stable and clean throughout the test. Not attached.

Flyash. Total : 0.027 mg flyash/gm fuel, measured at the end of test. Afterburner temperature was about 1050°F.

Test 12.

Flyash Distribution

Plate		mg/gm
1	(>9.2μ)	0.007
2		0.004
3		0.001
4		-
5		0.003
6		0.005
7	(<0.3μ)	0.007

Comments. 1. This is an exceptionally clean burn if measured only in terms of particulate.

2. There were no visible changes of primary furnace performance as the afterburner cooled down.

Chemical Results.

Chemical	Mole fraction (ppm)
CO (two and one-half hours after A.B. shutdown)	210
CO (three hours after A.B. shutdown)	310
CO (three and one-half hours after A.B. shutdown)	30

Comments. 1. No other chemical tests were made.

2. It would seem that these levels of CO, for this period of time, are not sufficient to produce the toxicological effects noted below.

Test 12.

Biomonitoring Results. (Dilution ratio; air: effluent = 6.)

Plants. Not tested.

Rats.

Number of control rats.	One.
Number of exposed rats.	Five.

Blood Work

Function	Hb(g/100 ml)	% CO	W.B.C.	Hematocrit	MCHC
Pre test	16.0 ± 0.3	0.8 ± 0.4	16,200 ± 3000	46.6 ± 1.4	34.4 ± 0.6
Test	15.5 ± 0.5	17.8 ± 1.4	10,700 ± 1700	46.0 ± 1.4	33.5 ± 0.5
Control(1)	15.8	1.0	12,400	44.0	35.9

Enzymes

	SGOT	SGPT
Exposed	106 ± 18	11 ± 5
Control	I.C.	I.C.

Necropsy. No findings, except, one of the surviving rats had dark brown circular areas on all lobes of lungs.

Comments. 1. One rat died during the exposure. His HbCO level was 70% which was not included in computation of the "Test" average and mean deviation in the table.

2. All other rats quickly recovered when removed from chamber.

Test 13.

Constraints. Aerobic, continuously-fed, underfire air for first two hours (Fig. V), crossfire for last two hours (Fig. I). (We had to change furnaces in middle of the run because of blown fuse.)

Primary Furnace Temperature.	1650°F throughout.
Afterburner Temperature.	1800°F throughout.
Air/Fuel Ratio.	72% T.A. for first two hours and 140% T.A. for last two hours.
Fuel Consumption rate.	290 gms/hour throughout.
Length of test.	Four hours burning time. Three hours exposure time.

Combustion Results.

Flame. Good, consistent flame throughout both parts of test. No visible smoke or soot.

Flyash. Not measured.

Comments.

1. This was the shakedown run for the furnace used during the first two hours.
2. Throughout the last two hours, the G.C. - F.I.D. was used. No peaks >0.1 ppm.

Test 13.

Biomonitoring Results. (Dilution; air: effluent = 8)

Plants. Not tested.

Rats.

Number of control rats. One.

Number of exposed rats. Four.

Blood Work

Function	Hb(g/100 ml)	% CO	W.B.C.	Hematocrit	MCHC
Pre test	16.1 ± 0.9	0.8 ± 0.4	15,100 ± 2,400	49.0 ± 1.4	32.8 ± 1.2
Test	15.1 ± 0.7	4.1 ± 2.8	15,600 ± 4,000	46.5 ± 0.6	32.5 ± 1.3
Control(1)	15.4	0	13,400	46	33.5

Enzymes

	SGOT	SGPT
Exposed	119 ± 39	31 ± 8
Control	120	59

Necropsy Findings : All of the exposed rats had what appeared to be fresh hemorrhagic areas of various sizes in the lung tissues. Also the lymph follicles of the exposed rats on the cut surface of the spleen were more prominent than usual.

Test 14.

Constraints. Anaerobic, continuously-fed, auger, crossfire air (across tube).

Primary Furnace Temperature.	1550°F
Afterburner Temperature.	1600°F
Air/Fuel Ratio.	135% T.A.
Fuel Consumption rate.	190 gms/hour.
Length of test.	Five hours burning time. Three hours exposure time.

Combustion Results. Good, consistent flame. No flyash measurements made.

Biomonitoring Results. (Dilution ratio; air: effluent = 6.)

Rats.

Number of control rats.	One.
Number of exposed rats.	Four.
Length of exposure.	Three hours.

Blood Work

Function	Hb(g/100 ml)	% CO	W.B.C.	Hematocrit	MCHC
Pre test	15.9 ± 1.0	0.8 ± 0.4	15,300 ± 3,000	48.2 ± 2.6	33.0 ± 1.2
Test	14.7 ± 1.4	0 ± 0	18,800 ± 2,500	44.5 ± 3.0	33.0 ± 1.1
Control(1)	15.8	0	15,100	46	34.3

Test 14.

Enzymes

	SGOT	SGPT
Exposed	194 ± 41	33 ± 4
Control	240	48

Comments. 1. No significant necropsy findings.

Test 15.

Constraints. Aerobic, continuously-fed, crossfire air.

Primary Furnace Temperature. 1650°F

Afterburner Temperature. 1800°F

Air/Fuel Ratio. 150% T.A.

Fuel Consumption rate. 300 gms/hour.

Length of test. Two hours burning time.

Combustion Results.

Flame. Same as test #13 with crossfire air in primary.

Flyash. Total 0.0090 mg flyash/gm fuel

Distribution

Plate		mg/gm
1	(>9.2μ)	0.0003
2		0.0003
3		0.0033
4		0.0020
5		0.0016
6		0.0003
7	(<0.3μ)	0.0010

Comments. 1. This test involved only particulate sampling. No chemical or toxicological data was taken.

2. Note the very low particulate production values. This was double-checked; the values were reproducible within 20%.

PS

APPENDIX III.

Polystyrene

1. Form. Pelletized. Styron®, general purpose. Courtesy of Dow Chemical Co.

2. Proximate Analysis.

Moisture	0.36%
Volatile	99.7%
Fixed Carbon	0%
Ash	0%

3. Nature of residue. None.

4. C, H, N analysis.

C - 92.45%
H - 7.55%
N - 0%

5. Air/fuel values at 100% theoretical air.

$$\frac{\text{Moles of air}}{\text{mole of plastic}} = 47.7$$

$$\frac{\text{ft}^3 \text{ of air}}{\text{gm of fuel}} = 0.388$$

at p = 76 cm, T = 20°C
at point of air flow
rate measurement.

Tests 1, 2, and 3. Batch burning. Crucible with 25 grams of PS inserted in 1500°F afterburner tube, about 12" from bottom of tube.

No visible flame for about one minute. Visible flame for about four minutes. No residue. There was too much soot and smoke present before and after ignition to obtain chemical analysis of effluent.

Plants and animals apparently unaffected by the cumulative (one-hour) acute exposure. No necropsies performed.

From these three batch tests and from other batch tests performed during last three years, we have observed that the degree of soot or smoke formation depends strongly upon the temperature of the fuel bed, in the absence of crossfire air.

Test 4.

Constraints. Aerobic, continuously-fed, auger, crossfire air.

Primary Furnace Temperature.	1650°F.
Afterburner Temperature.	1650°F.
Air/Fuel Ratio.	80%. T.A.
Fuel Consumption rate.	250 gms/hour.
Length of test.	Eight hours burning time. Six hours exposure time.

Combustion Results.

Flame. Consistent ignition, good flame, attached to auger.

Feeding difficulties. More difficult to feed than P.E. Auger tends to bind in its guide, especially at low feed rates.

Flyash. Total 0.034 mg flyash/gm fuel.

Distribution

Plate		mg/gm
1	(>9.2μ)	0.0012
2		0.0056
3		0.0006
4		0.0074
5		0.0089
6		0.0054
7	(<0.3μ)	0.0054

Test 4.

Comments. These low values of particulate production were characteristic of polystyrene in the cross fire air configuration.

Chemical Results. Carbon monoxide ranged from 2000 ppm to 9000 ppm. No other tests made.

Biomonitoring Results. (Dilution; air: effluent = 8.5.)

Plants. Not affected.

Rats.

Number of control rats.	One.
Number of exposed rats.	Two.
Length of exposure.	Six hours.

Observations. Only gross observations were made. The control rat seemed unaffected, while the test rats became very unresponsive to various stimuli, such as tapping on the chamber window. Symptoms suggest elevated HbCO in blood.

Tests 5 & 6.

Constraints. Aerobic, continuously-fed, auger, crossfire air.

Primary Furnace Temperature.	1650°F.
Afterburner Temperature.	1700°F.
Air/Fuel Ratio.	80%. T.A.
Fuel Consumption rate.	250 gms/hour.
Length of test.	Six hours burning time each test. Four hours exposure time each test.

Combustion Results.

Flame. Same as Test #4.

Feeding difficulties. None.

Flyash. Total 0.016 mg flyash/gm fuel.

Distribution

Plate		mg/gm
1	($>9.2\mu$)	0.0016
2		0.0020
3		0.0024
4		0.0040
5		0.0021
6		0.0021
7	($<0.3\mu$)	0.0022

Chemical Results. None. Unable to control drift on GC-MS readings.

Tests 5 & 6

Biomonitoring Results. (Dilution; air: effluent = 7.)

Plants. No apparent effects.

Rats.

Number of control rats.	One (total).
Number of exposed rats.	Five (total).
Length of exposure.	Four hours (each test).

Blood Work

Function	Hb(g/100 ml)	% CO	W.B.C.	Hematocrit	MCHC
Pre test	14.3 ± 0.2	N.D.	22,000 ± 4,000	43.6 ± 1.6	32.7 ± 1.0
Test	14.1 ± 0.5	N.D.	22,700 ± 7,700	42.0 ± 0.5	33.3 ± 1.4
Control(1)	14.3	N.D.	28,000	44	32.5

Enzymes

	SGOT	SGPT
Exposed	106 ± 13	33 ± 3
Control	146	38

Necropsy Results. No significant findings.

Comments. 1. HbCO not determined because of poor procedure and reagents. The behavior of the rats during the test may have indicated elevated HbCO. They were slow in responding to taps on the window. Very clumsy movement. Rapid breathing.

Tests 7 & 8

Constraints. Aerobic, continuously-fed, auger, crossfire air.

primary Furnace Temperature.	1550°F.
Afterburner Temperature.	1725°F.
Air/Fuel Ratio.	110% T.A. for first hour (no exposures). 150% T.A. for rest of test.
Fuel Consumption rate.	225 gms/hour.
Length of test.	Eight hours burning time. Six hours exposure time.

Combustion Results.

Flame. Excellent flame throughout test. Continuous ignition. Flame attached to auger guide most of the time. When not attached it appeared to engulf the whole volume.

Feeding difficulties. None.

Flyash. Total 0.0107 mg flyash/gm fuel, taken during last hour (150% T.A.).

Tests 7 & 8

Flyash Distribution

Plate		mg/gm
1	(>9.2μ)	0
2		0.0018
3		0.0009
4		0.0018
5		0.0018
6		0.0027
7	(<0.3μ)	0.0018

Comments. 1. The flyash production was so little that the values given above for the "Distribution" are subject to about 50% error.

Chemical Results.

Chemical	Mole fraction (ppm)	
	110% T.A.	150% T.A.
CO	<15	<15
CH_4	0.035	0.54
C_2H_2	0.015	0.112
C_2H_4	0.090	<0.01
Isobutane (tentative)	0.06	0.54
2-Methyl-1-Butane	0.45	2.0
Other C_5-C_7 compounds	3.70	2.9

Tests 7 & 8

Biomonitoring Results. (Dilution; air: effluent = 6.)

Plants. No effects observed.

Rats.

Number of control rats.	One.
Number of exposed rats.	Five.
Length of exposure.	Six hours.

Blood Work

Function	Hb(g/100 ml)	% CO	W.B.C.	Hematocrit	MCHC
Pre test	16.0 ± 0.3	8 ± 1.5	13,600 ± 1,100	46 ± 1.2	34.7 ± 0.3
Test	16.1 ± 0.1	10.0 ± 0.4	14,000 ± 2,300	47.8 ± 1.2	33.8 ± 0.8
Control(1)	14.5	8.3	11,700	46.0	31.5

Enzymes

	SGOT	SGPT
Exposed	88.6 ± 7.6	65 ± 5.4
Control	87	41.5

Necropsy. No significant findings.

Comments. 1. HbCO determination faulty because of calibrated "zero" being too high. Pre test average should be less than one, and test values would then be less than 2.5.

Tests 9 & 10.

Constraints. Anaerobic, continuously-fed, auger, crossfire across tube, but not across fuel.

Primary Furnace Temperature. 1950°F.

Afterburner Temperature. 1700°F.

Air/Fuel Ratio. 150%.T.A.

Fuel Consumption rate. 258 gms/hour.

Length of test. Ten hours burning time each test.
Six hours exposure time each test.

Combustion Results.

Flame. Very hot-looking flame, continuous ignition, attached to auger guide for full test. It took about one hour to establish stable flame in this configuration.

Feeding difficulties. None.

Flyash. Total 0.0508 mg flyash/gm fuel.

Distribution

Plate		mg/gm
1	(>9.2μ)	0.0128
2		0.0120
3		0.0112
4		0.0082
5		0.0040
6		0.0016
7	(<0.3μ)	0.0008

Tests 9 & 10

Comments. 1. By decreasing the temperature of the primary furnace to 1825°F, the soot production was reduced by a factor of about 2.5. The reduction occurred mainly in the first three plates (larger sizes).

Chemical Results.

Chemical	Mole fraction (ppm)
CO	<22 ppm
all hydrocarbons	<0.1 ppm

Comments. 1. When temperature of primary furnace was decreased to 1825°F, there were six compounds (hydrocarbons) detectable by F.I.D. with a total concentration of 2.1 ppm.

Biomonitoring Results. (Dilution; air: effluent = 7.)

Plants. No effects observed. This particular group of plants was allowed to grow through the flower and seed phases. Still not different from controls.

Rats.

Number of control rats.	One.
Number of exposed rats.	Five.
Length of exposure.	Six hours.

Tests 9 & 10.

Blood Work

Function	Hb(g/100 ml)	% CO	W.B.C.	Hematocrit	MCHC
Pre test	16.6 ± 0.3	N.D.	13,900 ± 2,000	46.6 ± 0.6	35.6 ± 0.4
Test	15.0 ± 0.4	N.D.	12,800 ± 1,900	43.2 ± 0.7	34.8 ± 0.7
Control(1)	15.8	N.D.	10,200	44.0	34.2

Enzymes

	SGOT	SGPT
Exposed	67 ± 24	27 ± 6
Control	72	34

Necropsy. No significant findings.

PS

Test 11.

Constraints. Aerobic, continuously-fed, auger, crossfire air. Afterburner turned off one hour after exposure had begun to determine temperature threshold for clean burning.

Primary Furnace Temperature. 1550°F throughout.

Afterburner Temperature. 1800°F initially.

Air/Fuel Ratio. 150%. T.A.

Fuel Consumption rate. 200 gms/hour.

Length of test. Eight hours burning time.
Three hours exposure time.

Combustion Results. Flame was continuous, attached and apparently clean throughout test.

Chemical Results.

1. Initially no GC - F.I.D. peaks greater than 0.1 ppm.
2. When afterburner reached 1400°F, several peaks appeared, but still less than 1 ppm.
3. When afterburner reached 1300°F, nine peaks present. Total of about 5 ppm equivalent methane.
4. When afterburner reached 1250°F, total of fourteen peaks with total of about 20 ppm equivalent methane.
5. Unfortunately, T.C. detector not working, so no CO results available. Data from HbCO for rats seems to indicate that there wasn't a great deal of CO

Test 11.

until 1250°F. (A later test performed for CO determination indicated CO in significant quantities (100 to 1000 ppm) for afterburner temperatures below 1250°F.)

Biomonitoring Results. (Dilution; air: effluent = 7.)

Plants. None tested.

Rats.

Number of control rats.	One.
Number of exposed rats.	Three.
Length of exposure.	Three hours. Removed when afterburner had reached 1250°F.

Blood Work

Function	Hb(g/100 ml)	% CO	W.B.C.	Hematocrit	MCHC
Pre test	17.0 ± 0.1	0	14,100 ± 1,200	48.0 ± 0.3	35.5 ± 0.2
Test	17.6 ± 0.4	3.0 ± 1.0	9,800 ± 200	48.5 ± 1.5	36.4 ± 0.6
Control (1)	16.7	3.0	10,000	48	37.1

Comments. 1. No necropsies performed.

2. There were too few rats involved in this test to draw extensive conclusions. The lack of increase of HbCO may be a significant result.

Test 12.

Constraints. Aerobic, continuously-fed, pneumatic feed into auger guide. Pyrolized fuel and air forced to exit through slot in auger guide (Fig. I).

Primary Furnace Temperature.	1650°F.
Afterburner Temperature.	1800°F.
Air/Fuel Ratio.	177% T.A. for first hour of exposure. 120% T.A. for remainder of test (three hours)
Fuel Consumption rate.	220 gms/hour for first hour. 325 gms/hour for last three hours.
Length of test.	Six hours burning time. Four hours exposure time.

Combustion Results.

Flame. Very clean-looking burn. Continuous ignition with flame attached to auger guide.

Feeding difficulties. None.

Flyash. Not measured.

Chemical Results. Using GC - F.I.D. all peaks below limit of detectability (<0.1 ppm equivalent methane).

PS

Test 12.

Biomonitoring Results. (Dilution; air: effluent = 6.)

Plants. Not exposed.

Rats.

Number of control rats.	One.
Number of exposed rats.	Four.
Length of exposure.	Four hours.

Blood Work

Function	Hb(g/100 ml)	% CO	W.B.C.	Hematocrit	MCHC
Pre test	16.2 ± 0.8	1.0 ± 0.1	15,800 ± 3,000	47.8 ± 1.6	33.3 ± 0.7
Test	17.2 ± 1.4	2.6 ± 1.0	13,700 ± 3,200	48.8 ± 1.7	35.3 ± 1.9
Control(1)	16.2	0	15,300	45.0	36.0

Enzymes

	SGOT	SGPT
Exposed	73 ± 28	28 ± 6
Control	100	34

Necropsy Findings: There was the occurrence of what appeared to be heavy carbon deposits in the bronchial and lung tissue of 2 of the exposed rats. Tissues were taken for histo-pathology of the bronchi and lungs of these rats. There were no significant findings.

PS

Test 13.

Constraints. Anaerobic, continuously-fed, auger, crossfire air across auger guide.

Primary Furnace Temperature.	1700°F.
Afterburner Temperature.	1800°F.
Air/Fuel Ratio.	120% T.A. for first hour.
	360% T.A. for remainder of test.
Fuel Consumption rate.	264 gms/hour for first hour.
	79 gms/hour for remainder of test.
Length of test.	Five hours burning time.
	Three hours exposure time.

Combustion Results.

Flame. Moderately good flame (unattached) for first hour. Relatively poor flame thereafter. Although attached and partially premixed, looked like a candle-flame.

Flyash. Total 0.282 mg flyash/gm fuel, measured during last hour (@360% T.A.).

Test 13.

Flyash Distribution

Plate		mg/gm
1	(>9.2μ)	0.0445
2		0.0490
3		0.0490
4		0.0471
5		0.0509
6		0.0292
7	(<0.3μ)	0.0115

Comments. The angle of the crossfire air was such that mixing was not as good as in other tests. The high air flow also cooled the tube too much, thus cooling the fuel and yielding different pyrolysis products.

Chemical Results.

Chemical	Mole fraction (ppm)	
	120% T.A.	360% T.A.
CH_4	2.0	1.5
Isopropanol	-	4.6
Unknown C_5 Compound	-	0.5
Hexane	-	13.6
n-Pentane	0.3	-

Test 13.

Qualitative Analyses. From water traps associated with particulate measurement: Small amounts of chloride, ammonium.

Biomonitoring Results. (Dilution; air: effluent = 6.)

Plants. None tested.

Rats.

Number of control rats.	One.
Number of exposed rats.	Four.
Length of exposure.	Three hours.

Blood Work

Function	Hb(g/100 ml)	% CO	W.B.C.	Hematocrit	MCHC
Pre test	16.9 ± 0.6	3.8 ± 0.1	15,800 ± 1,800	49.0 ± 0.5	34.8 ± 0.9
Test	16.9 ± 0.9	3.5 ± 0.8	16,000 ± 2,100	50.8 ± 2.3	33.0 ± 0.9
Control	16.7	0	15,300	51.0	32.7

Enzymes

	SGOT	SGPT
Exposed	125 ± 60	31 ± 13
Control	100	28

Comments. 1. No significant necropsy findings.

PS

Test 14.

Constraints. Anaerobic, continuously-fed, auger, crossfire air.

Primary Furnace Temperature.	1750°F.
Afterburner Temperature.	1400°F.
Air/Fuel Ratio.	143%. T.A.
Fuel Consumption rate.	270 gms/hour.
Length of test.	Six hours burning time. Four hours exposure time.

Combustion Results.

Flame. Much better flame than in test #13. Attached to auger guide. Continuous ignition.

Feeding difficulties. Some clogging. Changed auger to solve problem.

Flyash. Total 0.056 mg flyash/gm fuel.

Distribution

Plate		mg/gm
1	(>9.2μ)	0.0019
2		0.0001
3		0.0004
4		0.0007
5		0.0010
6		0.0007
7	(<0.3μ)	0.0009

Test 14.

Comments. 1. Plates two and six were found not to be in proper position at conclusion of test. There may have been excessive carryover from these two plates.

Chemical Results. No peaks (F.I.D.) greater than 0.1 ppm.

Biomonitoring Results. (Dilution; air: effluent = 6.)

Plants. Not tested.

Rats.

Number of control rats. None.

Number of exposed rats. Five.

Length of exposure. Four hours.

Blood Work

Function	Hb(g/100 ml)	% CO	W.B.C.	Hematocrit	MCHC
Pre test	16.3 ± 0.3	0	17,900 ± 4,200	51.4 ± 0.8	31.8 ± 0.4
Test	17.4 ± 0.1	1.5 ± 1.5	12,800 ± 4,500	50.8 ± 1.0	34.2 ± 0.4

Enzymes for Exposed Rats.

SGOT	SGPT
113 ± 15	33 ± 8

G

APPENDIX IV

Recipe Garbage

The first three tests were to establish a burnable recipe, representative of municipal trash without plastics. One result from the recipe burns is that there was created a small group of scientists and technicians with a psychosomatic allergy to certain foods.

Test #1. Recipe : 75% Sawdust
15% Coffee
10% Cornmeal

This was difficult to keep ignited without excessive binding within auger guide.

Test #2. Recipe : 91% Cream of Wheat
9% Crisco® oil

Same difficulties as in test #1, but not quite as severe. Primary furnace reached about 1100°F in spite of difficulties.

Test #3. Recipe : 77% Grape Nuts Cereal
23% Cream of Wheat

This yielded somewhat better results. The primary furnace easily reached 1100°F.

Test #4. Recipe : 54% Grape Nuts Cereal

27% Ground coffee

19% Sawdust

This was a fairly good test. The air/fuel ratio was about 400% T.A., and yet the primary furnace reached 1350°F with an afterburner temperature of about 1500°F. In spite of the fairly continuous flame and somewhat higher temperature, the effluent was still somewhat reminiscent of a bake sale. There were very few feeding difficulties and no visible soot or smoke.

Tests #5 and 6. Recipe : 45% Grape Nuts Cereal

40% Sawdust

15% Ground coffee

The primary furnace reached about 1250°F with 1700°F in the afterburner. Continuous flame with some difficulties. The combustion air was in the usual crossfire mode; the air/fuel = 400% T.A.

Carbon monoxide levels ranged from 0.3% to 1%. Both one- and two-week old plants were exposed for six hours each test without any observed effects. Dilution ratio (air: effluent) = 10 for both tests.

Test #7. Same as tests 5 & 6 except that it was terminated after only a two-hour exposure due to lack of proper burning.

Tests #8 and 9. Same as tests 5, 6 and 7. However, animals were tested instead of plants, and no chemical analyses were made. The burning was only moderately good.

(Test #8).

Rats.

Number of control rats.	One.
Number of exposed rats.	Five.
Length of exposure.	Six hours.

Blood Work

Function	Hb(g/100 ml)	% CO	W.B.C.	Hematocrit	MCHC
Pre test	15.0 ± 0.4	N.D.	18,000 ± 3,000	45 ± 1.6	33.5 ± 0.6
Test	14.2 ± 0.3	N.D.	1,800 ± 8,500	43.0 ± 1.0	33.0 ± 0.4
Control	14.9	N.D.	14,300	48.0	31.0

Enzymes

	SGOT	SGPT
Exposed	123 ± 5	25 ± 3
Control	151	22

Comments. 1. No significant necropsy findings.

(Test #9).

Rats.

Number of control rats.	One.
Number of exposed rats.	Five.
Length of exposure.	Six hours.

Blood Work

Function	Hb(g/100 ml)	% CO	W.B.C.	Hematocrit	MCHC
Pre test	15.0 ± 0.4	0	17,900 ± 3,100	44.8 ± 0.9	33.4 ± 0.7
Test	16.0 ± 0.5	0	18,800 ± 3,300	44.2 ± 2.4	33.2 ± 1.0
Control	14.7	0	20,900	51.0	28.8

Enzymes

	SGOT	SGPT
Exposed	121 ± 50	34 ± 5
Control	139	32

Comments. 1. No significant necropsy findings.

Tests #10 & 11.

Constraints. Aerobic, continuously-fed, auger feed, crossfire air.

Primary Furnace Temperature.	1400°F to 1500°F.
Afterburner Temperature.	1800°F.
Air/Fuel Ratio.	350% T.A. (estimated).
Fuel Consumption rate.	133 gms/hour.
Length of test.	Seven hours burning time each test. Six hours exposure time each test.

Recipe used:

50% Grape Nuts Cereal
25% Ground Coffee
25% Sawdust

Combustion Results.

Flame. Relatively poor in spite of generally continuous ignition. Much of the burning took place after fuel fell from auger guide to ash tray.

Feeding difficulties. Difficult to prevent jamming of auger.

Flyash. Total 0.115 mg flyash/gm fuel

Tests 10 & 11.

Flyash Distribution

Plate		mg/gm
1	(>9.2μ)	0.014
2		0.017
3		0.018
4		0.018
5		0.010
6		0.010
7	(<0.3μ)	0.028

Comments. 1. Particulate measurement accomplished when primary furnace at 1500°F.

2. Virtually no ash residue left in tray. About 98% reduction (by weight). Proximate analysis of this residue yielded about 18% volatile matter and moisture.

Chemical Results.

Chemical	Mole fraction (ppm)
CO	14 - 100
CH_4	2.0
C_2H_2	4.0
CH_2O	0.04
C_4 and C_5 Compounds	0.27

Tests 10 & 11.

Comments. 1. Carbon monoxide levels decreased with increase of primary furnace temperature.

2. The F.I.D. measurements reported here were taken from the same gas sample for which CO was 14 ppm.

Biomonitoring Results. (Dilution; air: effluent = 6.5.)

Plants. No effects observed.

Rats.

Number of control rats.	One.
Number of exposed rats.	Five.
Length of exposure.	Six hours.

Blood Work

Function	Hb(g/100 ml)	% CO	W.B.C.	Hematocrit	MCHC
Pre test	15.3 ± 0.4	5.7 ± 0.5	13,000 ± 2,500	42.8 ± 1.9	36.1 ± 0.3
Test	14.4 ± 0.3	10.5 ± 0.3	13,000 ± 1,700	43.0 ± 1.3	33.8 ± 0.8
Control	15.8	7.0	15,100	45	35.1

Comments. 1. Necropsies yielded no significant findings.

Tests 12 and 13.

Constraints. Anaerobic, continuously-fed, auger, crossfire air across auger guide.

Primary Furnace Temperature. 1100°F - 1200°F.

Afterburner Temperature. 1800°F.

Air/Fuel Ratio. 350% T.A. (estimated).

Fuel Consumption rate. 150 gms/hour.

Length of test. Seven hours burning time each test.
Six hours exposure time each test.

Recipe used:
50% Ground Coffee
30% Grape Nuts Cereal
20% Sawdust

Combustion Results.

Flame. Same as in tests 10 & 11 but better attachment of flame to auger guide.

Feeding difficulties. Difficult to feed. Much binding and clogging.

Flyash. Not measured.

Chemical Results. Five hydrocarbons detected, not identified. All less than 0.1 ppm.

Tests 12 and 13

Biomonitoring Results. (Dilution; air: effluent = 6.)

Plants. No effects observed.

Rats.

Number of control rats.	One.
Number of exposed rats.	Five.
Length of exposure.	Six hours.

Blood Work

Function	Hb(g/100 ml)	% CO	W.B.C.	Hematocrit	MCHC
Pre test	17.1 ± 0.2	<1	18,500 ± 1,500	48.7 ± 1.5	35.2 ± 1.0
Test	17.1 ± 0.3	3.3 ± 2.0	18,100 ± 2,000	47 ± 1.6	36.5 ± 0.9
Control	17.4	0	16,900	47.0	37.0

Enzymes

	SGOT	SGPT
Exposed	70 ± 17	22 ± 5
Control	60	24

Comments. No significant necropsy findings.

PP

APPENDIX V

Polypropylene

1. Form. Pelletized. Courtesy of Hercules, Inc.

2. Proximate Analysis.

Moisture	1%
Volatile	99%
Fixed Carbon	0%
Ash	0%

3. Nature of residue. None ever present.

4. C, H, N analysis.

C - 85.7%

H - 14.3%

N - 0%

[However, tests on the material indicated traces of Cl^- and nitrogen.]

5. Air/fuel values at 100% theoretical air.

$$\frac{\text{Moles of air}}{\text{mole of plastic}} = 21.4$$

$$\frac{\text{ft}^3 \text{ of air}}{\text{gm of fuel}} = 0.431$$

at $p = 76$ cm, $T = 20°C$

at point of air flow

rate measurement.

Test 1.

Constraints. Aerobic, continuously-fed, auger, crossfire air.

Primary Furnace Temperature. 1500°F.

Afterburner Temperature. 1650°F.

Air/Fuel Ratio. 157%. T.A.

Fuel Consumption rate. 156 gms/hour.

Length of test. Eight hours burning time.
Four hours exposure time.

Combustion Results.

Flame. Continuous ignition. Dark flame attached to auger guide - the flame seemed to contain soot, even when premixed with air.

Feeding difficulties. None.

Flyash. Total 0.029 mg flyash/gm fuel.

Distribution

Plate		mg/gm
1	(>9.2μ)	0.0074
2		0.0032
3		0.0039
4		0.0039
5		0.0048
6		0.0032
7	(<0.3μ)	0.0029

Test 1.

Chemical Results. Used G.C. - F.I.D. No peaks greater than 0.1 ppm.

Biomonitoring Results. (Dilution;air:effluent = 6.)

Plants. Not tested.

Rats.

Number of control rats.	One.
Number of exposed rats.	Four.
Length of exposure.	Four hours.

Blood Work

Function	Hb(g/100 ml)	% CO	W.B.C.	Hematocrit	MCHC
Pre test	17.3 ± 0.2	2 ± 0	14,700 ± 4,000	48.6 ± 1.4	35.7 ± 0.9
Test	17.6 ± 0.4	1 ± 1	12,300 ± 2,400	52.3 ± 1.9	33.6 ± 0.6
Control	15.4	0	15,600	46	33.5

Enzymes

	SGOT	SGPT
Exposed	76 ± 6	25 ± 3
Control	65	27

Comments. 1. Necropsy results. Three of the four exposed rats had minor hemorrhagic areas on the dorsal surface of the right diaphragmatic lobes.

PP

Tests 2 and 3.

Constraints. Aerobic, continuously-fed, pneumatic feed.

Primary Furnace Temperature.	1850°F.
Afterburner Temperature.	1650°F.
Air/Fuel Ratio.	96% T.A. for test #2 and 83% T.A. for test #3.
Fuel Consumption rate.	217 gms/hour for test #2 and 266 gms/hour for test #3.
Length of test.	Eight hours burning time for each. Four hours exposure time for each.

Combustion Results.

Flame. Much brighter flame than in test #1. Continuous ignition. Attached near inlet.

Feeding difficulties. None.

Flyash. Total 0.058 mg flyash/gm fuel at 83% T.A. Not measured at 96% T.A.

Tests 2 and 3.

Flyash Distribution

Plate		mg/gm (83% T.A.)
1	(>9.2μ)	0.0030
2		0.0010
3		0.0023
4		0.0026
5		0.0085
6		0.0130
7	(<0.3μ)	0.0270

Chemical Results.

	Chemical	Mole fraction (ppm)	
		96% T.A.	83% T.A.
	CH_4	15	450
	C_2H_6	15	240
Tentative Identification	CH_3OH	-	2.5
	1 - Butyne	-	2.5
	C_6H_6	2.0	15
	Toluene	1.5	4.0

Qualitative Analyses. From water traps associated with particulate measurement. Small amounts of chloride, ammonium, NO_x. Trace of cyanide.

Tests 2 and 3.

Comments. T.C. detector and M.S. interface not operable during these tests, so no CO measurements.

Biomonitoring Results. (Dilution; air: effluent = 8.)

Plants. Not tested.

Rats.

Number of control rats.	One each test.
Number of exposed rats.	Four each test(Total of eight).
Length of exposure.	Four hours.

Blood Work

Function	Hb(g/100 ml)	% CO	W.B.C.	Hematocrit	MCHC
Pre test	15.2 ± 0.3	1.5 ± 0.3	15,700 ± 2,500	49.5 ± 0.8	31.0 ± 0.7
Test #2	14.8 ± 0.7	11.5 ± 2.1	13,000 ± 1,800	49.0 ± 2.2	30.3 ± 0.9
Test #3	16.1 ± 0.4	19.1 ± 2.4	13,200 ± 2,000	50.8 ± 0.4	31.7 ± 0.6
Control(2)	15.1	0	17,400	52	29.1

Comments. 1. Rats for both tests pre tested at same time.

2. Control values are the average values from the two rats.

3. No SGOT or SGPT performed.

4. Necropsies indicated minor abnormalities of lungs of exposed rats. Histology negative.

Test 4.

Constraints. Anaerobic, continuously-fed, auger, crossfire across auger guide.

Primary Furnace Temperature. 1650°F.

Afterburner Temperature. 1700°F.

Air/Fuel Ratio. 140% T.A.

Fuel Consumption rate. 136 gms/hour.

Length of test. Eight hours burning time.
Four hours exposure time.

Combustion Results.

Flame. Very bright flame. Attached to auger guide. Continuous ignition.

Feeding difficulties. None.

Flyash. Total 0.015 mg flyash/gm fuel.

Distribution

Plate		mg/gm
1	(>9.2μ)	0.0077
2		0
3		0
4		0.0007
5		0.0018
6		0.0011
7	(<0.3μ)	0.0037

Test 4.

Chemical Results. Methane - 1.3 ppm.

No other peaks detectable.

Biomonitoring Results. (Dilution; air: effluent = 6.)

Plants. Not tested.

Rats.

Number of control rats.	One.
Number of exposed rats.	Four.
Length of exposure.	Four hours.

Blood Work

Function	Hb(g/100 ml)	% CO	W.B.C.	Hematocrit	MCHC
Pre test	17.7 ± 0.2	1.0 ± 0.5	13,400 ± 1,600	49.4 ± 0.7	35.8 ± 0.3
Test	16.1 ± 0.3	1.5 ± 1.2	9,200 ± 1,400	50.3 ± 0.9	32.0 ± 0.8
Control	17.2	0	9,700	53	32.5

Enzymes

	SGOT	SGPT
Exposed	99 ± 29	26 ± 8
Control	110	24

Comments. 1. No significant necropsy findings.

Tests 5 & 6.

Constraints. Aerobic, continuously-fed, auger, crossfire air.

Primary Furnace Temperature.	1800°F.
Afterburner Temperature.	1600°F.
Air/Fuel Ratio.	150% T.A.
Fuel Consumption rate.	240 gms/hour.
Length of test.	Eight hours burning time. Six hours exposure time.

Combustion Results.

Flame. Bright flame, attached to auger guide. Continuous ignition throughout both tests.

Flyash. Total 0.054 mg flyash/gm fuel

Distribution

Plate		mg/gm
1	(>9.2μ)	0.0096
2		0.0090
3		0.0103
4		0.0096
5		0.0090
6		0.0039
7	(<0.3μ)	0.0026

Tests 5 & 6.

Chemical Results. G.C. - F.I.D. used. No peaks greater than 0.1 ppm.

Biomonitoring Results. (Dilution; air: effluent = 6.)

Two complete sets of plants exposed, one set each test. No effects observed.

PF

APPENDIX VI

Phenol - Formaldehyde

1. Form. Milled bakelite switch-plates. Sieved to pass 16 mesh.

2. Proximate Analysis.

Moisture	3%
Volatile	63%
Fixed Carbon	20%
Ash	14%

3. Nature of residue. Contained about 24% volatile matter, no fixed carbon.

4. C, H, N analysis.

C - 57.4%

H - 5.58%

N - 2.38%

5. Air/fuel values at 100% theoretical air.

$$\frac{\text{Moles of air}}{\text{mole of plastic}} = 18.0$$

$$\frac{\text{ft}^3\text{ of air}}{\text{gm of fuel}} = 0.103$$

Assumptions. 1. $p = 76$ cm, $T = 20°C$ at point of air flow rate measurement.

2. All nitrogen contained in material goes to N_2, not NO_2.

3. Oxygen content of material is 34.64%, by weight.

Test 1.

Constraints. Aerobic, continuously-fed, pneumatic feed.

Primary Furnace Temperature.	1750°F.
Afterburner Temperature.	1450°F.
Air/Fuel Ratio.	450%. T.A.
Fuel Consumption rate.	300 gms/hour.
Length of test.	Four hours burning time. Three hours exposure time.

Combustion Results.

Flame. Clean flame. Continuous ignition, no particular point of attachment.

Feeding difficulties. None.

Flyash. Total 0.063 mg flyash/gm fuel.

Distribution

Plate		mg/gm
1	(>9.2μ)	0.023
2		0.005
3		0.005
4		0.010
5		0.008
6		0.006
7	(<0.3μ)	0.006

Test 1.

Chemical Results. Qualitative determinations from Andersen water trap. Small amounts of chloride, ammonium, cyanide. Trace of NO_x.

Biomonitoring Results. (Dilution; air: effluent = 6.)

Plants. Not tested.

Rats.

Number of control rats. Two.

Number of exposed rats. Four.

Length of exposure. Three hours.

Blood Work

Function	Hb(g/100 ml)	% CO	W.B.C.	Hematocrit	MCHC
Pre test	17.1 ± 0.7	1 ± 1	11,600 ± 2,400	47.3 ± 4.0	36.3 ± 2.4
Test	17.1 ± 0.4	1 ± 1	10,700 ± 1,000	52.5 ± 2.5	33.5 ± 2.6
Control (2) (average)	16.7	0.5	13,000	53.0	30.1

Enzymes

	SGOT	SGPT
Exposed	92 ± 17	34 ± 8
Control	133	40

Comments. 1. No significant necropsy findings.

Tests 2 & 3.

Constraints. Aerobic, continuously-fed, auger, crossfire air.

Primary Furnace Temperature.	1725°F.
Afterburner Temperature.	1700°F.
Air/Fuel Ratio.	425%. T.A.
Fuel Consumption rate.	300 gms/hour.
Length of test.	Five hours burning time each test. Three hours expsoure time each test.

Combustion Results.

Flame. Poor. Not very consistent ignition. No obvious attachment point. When attachment to auger occurs, good flame.

Flyash. Total 0.028 mg flyash/gm fuel.

Distribution

Plate		mg/gm
1	(>9.2μ)	0.0098
2		0.0070
3		0.0056
4		0.0042
5		0.0007
6		0.0007
7	(<0.3μ)	0.0004

Comments. 1. Residue contained 24% volatile matter and 77.3% ash.

Tests 2 & 3.

Chemical Results. Qualitative results from Andersen water trap : Small amount of chloride, trace amounts of ammonium, cyanide, NO_x.

Biomonitoring Results. (Dilution; air : effluent = 10.)

Plants. No effects observed.

Rats.

Number of control rats.	Two each test.
Number of exposed rats.	Four each test.
Length of exposure.	Three hours.

Blood Work

Function	Hb(g/100 ml)	% CO	W.B.C.	Hematocrit	MCHC
Pre test	15.8 ± 0.6	1 ± 1	13,800 ± 5,000	46.3 ± 1.0	35.5 ± 1.5
Test	16.0 ± 1.1	1 ± 1	12,100 ± 2,200	49 ± 4.0	32.7 ± 2.0
Control (4) (average)	15.8	0.8	13,200	50.5	30.6

Enzymes

	SGOT	SGPT
Exposed	120 ± 60	37 ± 10
Control	120	38

Comments. 1. No significant necropsy findings.

Test 4.

Constraints. Anaerobic, continuously-fed, auger, underfire across auger (Fig. V with the anaerobic auger guide).

Primary Furnace Temperature.	1400°F (average).
Afterburner Temperature.	1800°F.
Air/Fuel Ratio.	124%. T.A.
Fuel Consumption rate.	860 gms/hour.
Length of test.	Four hours burning time. Three hours exposure time.

Combustion Results.

Flame. Consistent burning, continuous ignition, attached to auger guide.

Flyash. Total 0.218 mg flyash/gm fuel

Distribution

Plate		mg/gm
1	(>9.2μ)	0.0600
2		0.0276
3		0.0380
4		0.0520
5		0.0160
6		0.0120
7	(<0.3μ)	0.0120

Test 4.

Comments. 1. The soot was very feathery. Much of the weight was due to condensed water, in spite of the fact that our collecting conditions were the same as usual. The temperatures of the collector were about the same as usual. No soot seen leaving the stack. Most likely formed within collector, with a release of water.
2. Residue had only 7% volatile matter.

Qualitative Analyses. From water traps associated with particulate measurement: Small quantities of chloride and cyanide. Trace quantities of ammonium and NO_x.

Biomonitoring Results. (Dilution; air: effluent = 10.)

Plants. No effects observed.

Rats.

Number of control rats.	Two
Number of exposed rats.	Four.
Length of exposure.	Three hours.

Blood Work

Function	Hb(g/100 ml)	% CO	W.B.C.	Hematocrit	MCHC
Pre test	15.7 ± 0.5	3 ± 2	17,300 ± 2,000	46.8 ± 2.4	33.6 ± 0.8
Test	16.1 ± 0.8	1.5 ± 1.5	13,600 ± 1,300	48.5 ± 2.0	33.2 ± 1.0
Control	15.7	3.0	18,000	48.5	32.4

Test 4.

Enzymes

	SGOT	SGPT
Exposed	121 ± 63	43 ± 30
Control	73	23

Comments. 1. No significant necropsy findings.

PF

Test 5.

1. Form. Glue. Courtesy of Borden's. Cascophen HL-69.

2. Proximate Analysis.

Moisture	29%
Volatile	32%
Fixed Carbon	0%
Ash	39%

3. Nature of residue. Only 5% volatile matter & moisture.

4. C, H, N analysis.

C - 37.6%

H - 4.7%

N - 0%

5. Air/fuel values at 100% theoretical air.

$$\frac{\text{Moles of air}}{\text{mole of plastic}} = 17.7$$

$$\frac{\text{ft}^3 \text{ of air}}{\text{gm of fuel}} = 0.148$$

Assumptions. 1. p = 76 cm, T = 20°C at point of air flow rate measurement.

2. Assume 39% is inert. Any oxygen contained in the inert material not available for combustion.

3. Assume 18.7% oxygen (by weight) in material. All of this available for combustion.

Test 5.

Constraints. Aerobic, continuously-fed, auger, underfire air (Fig. V).

Primary Furnace Temperature. 1400°F.

Afterburner Temperature. 1750°F.

Air/Fuel Ratio. 103% T.A.

Fuel Consumption rate. 430 gms/hour.

Length of test. Five hours burning time.
Three hours exposure time.

Combustion Results.

Flame. Quite good flame, when ignited. Difficult to maintain ignition.

Feeding difficulties. None.

Flyash. Total 0.116 mg flyash/gm fuel.

Distribution

Plate		mg/gm
1	(>9.2μ)	0.005
2		0.005
3		0.006
4		0.006
5		0.013
6		0.033
7	(<0.3μ)	0.048

Test 5.

Comments. 1. The flyash was gray to white, in contrast to the usual soot-black we usually obtained.

2. The flyash was hygroscopic with recrystallization. Immediately after exposure to room air (even though the plates were still hot), the ash "grew" into whiskers on the plate.

Chemical Results

Chemical	Mole fraction (ppm)
CH_4	16
C_3 Compound	<1

No other hydrocarbon peaks.

Qualitative Analyses. From water traps associated with particulate measurement. Small amount of ammonium. No chloride or cyanide or NO_x detected.

Biomonitoring Results. (Dilution; air: effluent = 8.)

Plants. No effects observed.

Rats.

Number of control rats.	Two.
Number of exposed rats.	Six.
Length of exposure.	Three hours.

Test 5.

Blood Work

Function	Hb(g/100 ml)	% CO	W.B.C.	Hematocrit	MCHC
Pre test	18.0 ± 0.8	1 ± 1	15,400 ± 2,300	53.8 ± 1.7	33.5 ± 1.1
Test	18.5 ± 1.4	1 ± 1	15,200 ± 1,600	53.2 ± 2.9	34.6 ± 1.4
Control (2) (average)	18.5	0	12,600	54.5	33.9

Enzymes

	SGOT	SGPT
Exposed	111 ± 26	30 ± 16
Control	79	22

Urine Analysis

Measurement	Color	pH	Volume (ml)	Protein (mg/100 ml)	Sugar	Ketone	Bilirubin	Blood
Pre test	Cloudy Light Straw	6.5	10.2	0 - 30	0	0	0	0
Test	Cloudy Light Straw	7.0	8.5	0 - 30	0	0	0	0

Test 5.

Examination of Sediment (average values/HPF).

Measurement	RBC	WBC	Epith. Cells	Bact.	Casts	Crystals
Pre test	0	0.6	0.3	3+	0	6 TRP 0.3 CaOX
Test	0	0	0	3+	0	6 TRP + amorph. phos.

Necropsy. No significant findings.

APPENDIX VII

Polycarbonate

1. Form. Pelletized. Hercules, Inc.

2. Proximate Analysis.

Moisture	0%
Volatile	83%
Fixed Carbon	17%
Ash	0%

3. Nature of residue. Char of conjugated hydrocarbons.

4. C, H, N analysis.

C - 75.8%

H - 5.14%

N - 0%

5. Air/fuel values at 100% theoretical air.

$$\frac{\text{Moles of air}}{\text{mole of plastic}} = 33.3$$

$$\frac{\text{ft}^3 \text{ of air}}{\text{gm of fuel}} = 0.283$$

Assumptions. 1. $p = 76$ cm, $T = 20°C$ at point of air flow rate measurement.

2. Assume 19% of material (by weight) is oxygen available for combustion.

Constraints. Aerobic, continuously-fed, pneumatic feed.

Primary Furnace Temperature. 2000°F (When operating properly).

Afterburner Temperature. 1800°F.

Air/Fuel Ratio. 150%. T.A.

Fuel Consumption rate. 375 gms/hour

Length of test. One hour burning time.

Combustion Results.

Flame. Very good, turbulent flame until feed clogs. Ignition temperature apparently well above melting point due to formation of conjugated compounds on surface.

Feeding difficulties. Would not feed for more than an hour without serious clogging.

Flyash. Total 0.047 mg flyash/gm fuel.

Distribution

Plate		mg/gm
1	(>9.2μ)	0.024
2		0.004
3		0.004
4		0.003
5		0.005
6		0.002
7	(<0.3μ)	0.005

Comments. Only one particulate sample taken. No plant or rat exposure.

APPENDIX VIII

Barex 210®

1. Form. Milled bottles obtained from Pepsi Cola.

2. Proximate Analysis.

Moisture	1%
Volatile	90%
Fixed Carbon	9%
Ash	0%

3. C, H, N analysis.

C - 65.8%

H - 6.4%

N - 17.5%

4. Air/fuel values at 100% theoretical air.

$$\frac{\text{Moles of air}}{\text{mole of plastic}} = 48.5$$

$$\frac{\text{ft}^3 \text{ of air}}{\text{gm of fuel}} = 0.272$$

Assumptions.
1. p = 76 cm, T = 20°C at point of air flow rate measurement.
2. Assume 10% of material is oxygen available for combustion.

Constraints. Aerobic, continuously-fed, auger, underfire air (Fig. V).

Primary Furnace Temperature.	1500°F.
Afterburner Temperature.	1800°F.
Air/Fuel Ratio.	about 105% T.A.
*Fuel Consumption rate.	about 300 gms/hour.
Length of test.	Four hours burning time. Two hours exposure time.

*This was not accurately determined.

Combustion Results.

Flame. Good flame, attached to auger guide. Continuous, rapid ignition.

Feeding difficulties. None.

Flyash. Total 0.080 mg flyash/gm fuel (approximately)

Distribution (approximate)

Plate		mg/gm
1	(>9.2μ)	0.020
2		0.010
3		0.017
4		0.007
5		0.007
6		0.003
7	(<0.3μ)	0.010

Chemical Results.

Chemical	Mole fraction(ppm)
CH_4	2.6
HCl	240
NO_x	measurement not made.

Biomonitoring Results. (Dilution; air:effluent = 6.)

Plants. Mustard and alfalfa looked a bit wilted when removed from chamber. However, the next day the topmost leaves were dead. Eventually, the whole plant died. Other plants unaffected.

Rats.

Number of control rats.	One.
Number of exposed rats.	Five.
Length of exposure.	Two hours.

Blood Work

Function	Total Hb(g/100 ml)	% CO	W.B.C.	Hematocrit	MCHC
Pre test	16.1 ± 0.8	0	17,700 ± 2,100	47.7 ± 2.4	33.8 ± 1.6
Test	15.8 ± 0.9	3.3 ± 2.8	15,200 ± 3,000	47.5 ± 2.6	33.3 ± 1.0
Controls(2)	16.5	0	21,600	51	32.4

Enzymes

	SGOT	SGPT
Exposed	104 ± 29	49 ± 23
Control	95	29

Comments. No significant necropsy findings.

APPENDIX IX

Styrene - Acrylonitrile

1. Form. Pelletized. Courtesy of Dow Chemical, Inc.

2. Proximate Analysis.

Moisture	1%
Volatile	99%
Fixed Carbon	0%
Ash	0%

3. Nature of residue. None.

4. C, H, N analysis.

C - 85.6%

H - 7.3%

N - 7.3%

[Limit of accuracy is about 0.1%. Tests indicated trace of Cl^- present.]

5. Air/fuel values at 100% theoretical air.

$$\frac{\text{Moles of air}}{\text{mole of plastic}} = 42.5$$

$$\frac{\text{ft}^3\text{ of air}}{\text{gm of fuel}} = 0.359$$

at p = 76 cm, T = 20°C

at point of air flow

rate measurement.

Constraints. Aerobic, continuously-fed, auger, underfire air.

Primary Furnace Temperature. 1800°F.

Afterburner Temperature. 1800°F.

Air/Fuel Ratio. 150% T.A.

Fuel Consumption rate. 365 gms/hour.

Length of test. Six hours burning time.

Four hours exposure time.

Combustion Results.

Flame. Very hot flame. Stable ignition, even with primary furnace electricity totally off. Very clean flame.

Feeding difficulties. None.

Flyash. Total 0.0101 mg flyash/gm fuel.

Distribution

Plate		mg/gm
1	(>9.2μ)	0.0093
2		0.0003
3		0
4		0.0005
5		0
6		0
7	(<0.3μ)	0

Chemical Results.

Chemical	Weight fraction (mg/gr of effluent)
HCl	216
Aldehyde-ketone	1.8
NO	4.0
NO_2	1.7
Cyanide	<0.1

Biomonitoring Results. (Dilution; air: effluent = 8.)

Plants. No effects observed.

Rats.

Number of control rats.	Four.
Number of exposed rats.	Eight.
Length of exposure.	Four hours.

Blood Work

Function	Hb(g/100 ml)	% CO	W.B.C.	Hematocrit	MCHC
Pre test	17.6 ± 1.0	0.6 ± 0.6	16,600 ± 3,000	53.0 ± 1.0	33.2 ± 3.0
Test	15.0 ± 2.4	0	13,900 ± 3,500	51.0 ± 4.4	30.0 ± 3.8
Control	16.3	0	17,850	50.8	31.2

Enzymes

	SGOT	SGPT
Exposed	143 ± 51	30 ± 26
Control	63	16

Urinalysis.

	Color	Spec. Grav.	Vol.	pH	Protein (mg/100 ml)	Sugar	Ketone	Bilirubin	Blood
Pre test	Cl.S.	1.011	11.0	6.1	0-Trace	0	0	0	0 - 5
Test	Cl.LS.	1.011	10.7	6.1	Tr - 30	0	0	0	*MOD-MKD
Control	LS.	1.003	21	6.0	Tr	0	0	0	5

Examination of Sediment avg./HPF

	RBC	WBC	Epith. Cells	Bact.	Casts	Crystals
Pre test	1.3	5	1.6	3.3	+	2 TRP 0.6 Ca Ox
Test	*	1.3	1	3+	0	8 TRP
Control	0	10	3	4+	0	no crystals

* 1 sample Red Brown and too dense with RBC's to read. Possibly due to blood left on tail after bleeding. Repeat urinalysis was performed next day. Qualitative Analysis showed 0 blood. Micro examination revealed 2 RBC/HPF.

Necropsy Findings. 2 of the four control rats had minor lung abnormalities. All exposed rats had minor abnormalities of kidneys or lungs. It is impossible to judge from gross observations whether or not they are due to inhalation of effluent. Histological studies yielded no remarkable findings.

ABS

APPENDIX X

Acrylonitrile - Butadiene - Styrene

1. Form. Pelletized. AM grade. Purchased from Marbon, Inc.

2. Proximate Analysis.

Moisture	1%
Volatile	98%
Fixed Carbon	1%
Ash	0%

3. Nature of residue. Never enough to characterize.

4. C, H, N analysis.

C - 85.5%

H - 7.5%

N - 6.4%

5. Air/fuel values at 100% theoretical air.

$$\frac{\text{Moles of air}}{\text{mole of plastic}} = 42.9$$

$$\frac{\text{ft}^3 \text{ of air}}{\text{gm of fuel}} = 0.361$$

at p = 76 cm, T = 20°C
at point of air flow
rate measurement.

Test 1.

Constraints. Aerobic, continuously-fed, auger feed, underfire air (Figure V).

Primary Furnace Temperature.	1650°F
Afterburner Temperature.	1750°F.
Air/Fuel Ratio.	169%. T.A.
Fuel Consumption rate.	375 gms/hour.
Length of test.	Six hours burning time. Four hours exposure time.

Combustion Results.

Flame. Very sensitive flame. Tends to soot easily; however, generally clean. Second flame attached to upper orifice while lower flame tends to engulf whole primary.

Feeding Difficulties. None.

Flyash. Total 0.0117 mg flyash/gm fuel.

Distribution

Plate		mg/gm
1	(>9.2μ)	0.0005
2		0.0005
3		0.0003
4		0.0005
5		0.0024
6		0.0021
7	(<0.3μ)	0.0053

Test 1.

Chemical Results.

Chemical	Mole fraction (ppm)
CH_4	2.4
HCl	17

Qualitative Analyses. From water traps associated with particulate measurement: Small amounts of chloride and ammonium.

Biomonitoring Results. (Dilution; air:effluent = 8.)

Plants. No effects observed.

Rats.

Number of control rats.	Two
Number of exposed rats.	Four
Length of exposure.	Four hours.

Blood Work

Function	Hb(g/100 ml)	% CO	W.B.C.	Hematocrit	MCHC
Pre test	14.9 ± 0.1	1 ± 1	15,400 ± 6,000	44.5 ± 0.9	33.6 ± 0.7
Test	15.5 ± 0.3	ND*	15,800 ± 1,000	48.4 ± 0.5	32.0 ± 0.3
Control	15.5	ND*	17,800	49	31.5

* Error in CO procedure for post-test results.

Enzymes

	SGOT	SGPT
Exposed	49 ± 21	24 ± 10
Control	49	56

Necropsy findings: All exposed rats had lung and kidney abnormalities. Lungs were generally enlarged and spongy. In two rats, the renal pelvis of the kidneys were dilated, and in the other exposed rats, the papilla were reddened. One control rat was normal, and the other had slightly spongy lungs, and the renal pelvis was slightly eroded.

Sections were submitted for histology. No remarkable results.

Test 2.

Constraints. Same as Test 1.

Primary Furnace Temperature.	1750°F.
Afterburner Temperature.	1820°F.
Air/Fuel Ratio.	150%. T.A.
Fuel Consumption rate.	353 gms/hour.
Length of test.	Six hours burning time. Four hours exposure time.

Combustion Results.

Flame. Flame engulfed entire volume of primary. Attached to upper orifice, auger guide. Also a very tenuous flame in first three or four inches of afterburner.

Flyash. Total 0.042 mg. flyash/gm fuel.

Distribution

Plate		mg/gm
1	(>9.2μ)	0.0003
2		0.0003
3		0.0023
4		0.0051
5		0.0105
6		0.0111
7	(<0.3μ)	0.0122

Chemical Results.

Chemical	Mole fraction (ppm)
HCl	92 to 420

Test 2.

Qualitative Analyses. From water traps associated with particulate measurement: Trace of ammonium, cyanide, NO_x.

Biomonitoring Results. (Dilution; air:effluent = 7.)

Plants. No effects observed.

Rats.

Number of control rats.	Two.
Number of exposed rats.	Four.
Length of exposure.	Four hours.

Blood Work

Function	Hb(g/100 ml)	CO%	W.B.C.	Hematocrit	MCHC
Pre Test	15.9 ± 0.3	0	17,000 ± 800	47.3 ± 0.6	33.5 ± 0.4
Test	15.4 ± 0.3	4.4 ± 2.4	16,200 ± 3,000	44.8 ± 2.2	34.5 ± 1.1
Control (2)	17.1	1	17,800	50.5	33.7

Enzymes

	SGOT	SGPT
Exposed	52 ± 31	33 ± 11
Control	56	28

Necropsy findings. No significant findings.

Tests 3 and 4.

Constraints. Same as test #1.

Primary Furnace Temperature.	1650°F.
Afterburner Temperature.	1800°F.
Air/Fuel Ratio.	150% T.A. to 180% T.A.
Fuel Consumption rate.	350 gms/hour.
Length of test.	Six hours burning time. Four hours exposure time.

Combustion Results.

Flame. Same as test #2.

Flyash. Total 0.078 mg flyash/gm fuel.

Distribution

Plate		mg/gm
1	(>9.2μ)	0.013
2		0.009
3		0.011
4		0.013
5		0.014
6		0.011
7	(<0.3μ)	0.007

Comments. Flyash very light and feathery.

Chemical Results. Data taken during startup period in test 3.

Tests 3 and 4.

Chemical	Mole fraction (ppm)
CH_4	19.4
No other hydrocarbon peaks.	
NO_x	1.6 to 10.

Qualitative Analyses. From water traps associated with particulate measurement: Small ammonium and NO_x.

Biomonitoring Results. (Dilution; air:effluent = 8.)

Plants. No effects observed.

Rats.

Number of control rats.	Four.
Number of exposed rats.	Twelve.
Length of exposure.	Four hours.

Blood Work

Function	Hb(g/100 ml)	% CO	W.B.C.	Hematocrit	MCHC
Pre test	18.2 ± 0.6	0	16,800 ± 4,100	51.5 ± 3.1	31.6 ± 2.6
Test	16.4 ± 0.9	1 ± 1	14,400 ± 2,500	50.6 ± 2.4	32.5 ± 1.7
Control (4)	16.6	0	17,500	49.5	33.9

Enzymes

	SGOT	SGPT
Exposed	74 ± 14	22 ± 9
Control	96	23

Comments. No significant necropsy findings.

APPENDIX XI

Polyurethane

1. Form. Gasket rope. ¼" Dia.

2. Proximate Analysis.

Moisture	1%
Volatile	98%
Ash	1%

3. Nature of residue. Not enough to characterize.

4. C, H, N analysis.

C - 65.6%

H - 9.5%

N - 2.9%

5. Air/fuel values at 100% theoretical air.

$$\frac{\text{Moles of air}}{\text{mole of plastic}} = 34.1$$

$$\frac{\text{ft}^3 \text{ of air}}{\text{gm of fuel}} = 0.291$$

Assumptions. 1. p = 76 cm, T = 20°C at point of air flow rate measurement.

2. All nitrogen becomes N_2 during combustion.

3. The material contains 21% oxygen (by weight), all of which is available for combustion.

Test 1.

Constraints. Aerobic, continuously-fed using extruder mechanism. Crossfire air.

Primary Furnace Temperature. 1550°F.

After burner Temperature. 1770°F.

Air/Fuel Ratio. 140%. T.A.

Fuel Consumption rate. 385 gms/hour.

Length of test. Three hours burning time.
Two and one-half hours exposure time.

Combustion Results.

Flame. Continuous ignition. Attached to the auger guide. Not much turbulence.

Feeding difficulties. None.

Flyash. Total 0.097 mg flyash/gm fuel.

Distribution

Plate		mg/gm
1	(>9.2μ)	0.077
2		0.007
3		0.005
4		0.003
5		0.003
6		0.002
7	(<0.3μ)	0.0003

Comments. Flyash was black and feathery except on plate #1 where more granular particles were trapped.

Test 1.

Chemical Results.

Chemical	Mole fraction (ppm)
NO	0.63
NO_2	2.12

Qualitative Analyses. From water traps associated with particulate measurement: Trace of ammonium.

Biomonitoring Results. (Dilution; air: effluent = 6.)

Plants. No effects observed.

Rats.

Number of control rats.	Four.
Number of exposed rats.	Six.
Length of exposure.	2½ hours.

Blood Work

Function	Hb (g/100 ml)	% CO	W.B.C.	Hematocrit	MCHC
Pre test	17.7 ± 0.4	0	12,500 ± 3,000	50.6 ± 2.0	35.0 ± 2.4
Test (6)	18.2 ± .72	0	10,000 ± 2,500	51.5 ± 2.2	35.2 ± 1.3
Control (4)	17.7	0	10,000	50.5	35.0

Test 1.

Enzymes

	SGOT	SGPT
Exposed	209 ± 36	23 ± 6
Control	180	18

Urinalysis

	Color	Spec. Grav.	Vol.	pH	mg/100 ml protein	Sugar	Ketone	Bilirubin	Blood
Pre test	LS	1.010	18.9	6.1	0	0	0	0	0
Test	Cl LS	1.010	17.0	6.0	0	0	0	0	0
Control	Cl LS	1.010	16.1	6.5	Trace	0	0	0	0

Examination of Sediment (average/HPF)

	RBC	WBC	Epith. Cells	Bact.	Casts	Crystals	Comments
Pre test	0.6	1	2.6	2+	0	AMPH. UREATES 2.5 TRP	occ. pinworms
Test	0.5	0.5	0.5	3+	0	2 Uric Acid AMPH. UREATES	occ. pinworms
Control	2	4	2	3+	0	7. 6 TRP	occ. pinworms

Necropsy Findings. No significant findings. One exposed rat had a liver lesion which appeared too old to be caused by exposure.

Test 2.

1. Form. Rigid Foam.

2. Proximate Analysis.

Moisture	3%
Volatile	88%
Fixed Carbon	5%
Ash	4%

3. Nature of residue. Not enough to characterize.

4. Rigid foam, 3' x 6', were cut into ½" x ½" x 3' strips to be fed through the wheels.

Constraints. Aerobic, quasi-continuous-feed using extruder wheels. Crossfire air.

Primary Furnace Temperature.	1100°F to 1700°F.
Afterburner Temperature.	1700°F.
Air/Fuel Ratio.	165% T.A. nominal.
Fuel Consumption rate.	210 gms/hour.
Length of test.	Three hours burning time. Two hours exposure time.

Test 2.

Combustion Results.

Flame. Good ignition when strip was present in burning zone. However, flame intermittent due to feeding problems.

Feeding difficulties. There was a slight pause between strips of material, with a loss of ignition temporarily.

Flyash. Not measured.

Biomonitoring Results. (Dilution; air : effluent = 7.)

Plants. No effects observed.

Rats.

Number of control rats.	One.
Number of exposed rats.	Four.
Length of exposure.	Two hours.

Blood Work

Function	Hb(g/100 ml)	% CO	W.B.C.	Hematocrit	MCHC
Pre test	15.2 ± 0.5	0	13,600 ± 2,600	47.3 ± 3.1	32.2 ± 2.4
Test	16.0 ± 1.0	0	16,000 ± 3,500	50.0 ± 1.8	32.1 ± 2.9
Control(1)	17.9	0	20,500	56.0	31.9

Test 2.

Enzymes

	SGOT	SGPT
Exposed	125 ± 13	48 ± 8
Control	176	37

Comments. No significant necropsy findings.

APPENDIX XII

Urea - Formaldehyde (Alpha - Cellulose Filled)

1. Form. Milled switch-plates. Sieved to pass 16 mesh.

2. Proximate Analysis.

Moisture	4%
Volatile	86%
Fixed Carbon	10%
Ash	0.1%

3. Nature of residue. 40.2% volatile. No fixed carbon.

4. C, H, N analysis.

C - 33.8

H - 5.7

N - 22.4

5. Air/fuel values at 100% theoretical air.

$$\frac{\text{Moles of air}}{\text{mole of plastic}} = 14.6$$

$$\frac{\text{ft}^3 \text{ of air}}{\text{gm of fuel}} = 0.124$$

Assumptions. 1. p = 76 cm, T = 20°C at point of air flow rate measurement.

2. Assume 38.1% (by weight) is bound oxygen available for combustion.

Test 1. (This test is typical of 10 batch tests done with urea-formaldehyde.)

Constraints. Batch test. 25 gm samples placed 12" from bottom of afterburner. Crucible not capped.

Primary Furnace Temperature. ---

Afterburner Temperature. 1350°F at center of verticle tube.

Air/Fuel Ratio about 400% T.A.

Combustion Results. Slow to ignite; took about one minute. After ignition, very tenuous flame. One minute after ignition, very intense flame for two minutes, and then out. Crucible temperature was raised about 500°F above its ambient.

Flyash was grayish-white and sublimed or dissociated at around 37°C. Probably ammonium bicarbonate or ammonium carbonate.

Chemical Results. Depending on what portion of the burn, we had 0 - 10 ppm acrolein, 0 - 150 ppm total aldehyde-ketone, 0 - 30 ppm HCN, 0 - 400 ppm NH_4^+, and 0 - 1000 ppm CO. The high numbers apply to either pre-ignition times with low afterburner temperature, or air/fuel ratios between 70% and 90%. The low numbers apply for the "intense burning" portion of the test, if adequate air was present and the afterburner was above 1500°F.

Test 1.

Biomonitoring Results. (Dilution; air : effluent ≈ 4.)

Plants. Were wilted within minutes after a test. Colors seemed more intense. Usually dead by the next day with some loss of color.

Rats.

Number of control rats.	One.
Number of exposed rats.	Two.
Length of exposure.	15 minutes to one hour.

Comments. The rats reacted immediately to the effluent. Their respiration rate increased sharply to the point of gasping. Within a few minutes they were in a convulsive coma, from which they quickly recovered, if soon removed from the exposure chamber.

Test 2.

Constraints. Aerobic, continuously-fed, auger, crossfire air.

Primary Furnace Temperature.	1430°F.
Afterburner Temperature.	1550°F.
Air/Fuel Ratio.	475% T.A.
Fuel Consumption rate.	175 gms/hour.
Length of test.	Ten hours burning time. Six hours exposure time.

Combustion Results.

Flame. Intermittent for first part of test. Not attached to auger guide. For latter part of test seemed to have continuous ignition, good turbulence, but still not an impressive flame.

Feeding difficulties. Much clogging of fuel and binding of the auger - to the extent of breaking one auger. Replaced during test.

Flyash. Total 0.186 mg flyash/gm fuel.

Distribution

Plate		mg/gm
1	(>9.2μ)	0.042
2		0.028
3		0.076
4		0.014
5		0.018
6		0.006
7	(<0.3μ)	0.002

Test 2.

Chemical Results.

Chemical	Mole fraction(ppm)
CO	100 - 300 during exposure.
Methane	2
Three other hydrocarbons	<0.1

Biomonitoring Results. (Dilution; air: effluent = 6.)

Plants. Exposed plants badly wilted after exposure. Wilted areas were dead within two days. Some leaves were unaffected and continued to grow well. Beans least affected.

Rats.

Number of control rats.	One.
Number of exposed rats.	Five.
Length of exposure.	Six hours.

Blood Work

Function	Hb(g/100 ml)	% CO	W.B.C.	Hematocrit	MCHC
Pre test	16.4 ± 0.2	0	16,500 ± 1,200	46.4 ± 0.7	35.4 ± 0.3
Test	17.3 ± 0.4	7.2 ± 1.2	17,800 ± 2,600	48.8 ± 1.6	34.7 ± 1.4
Control	17.6	0	26,000	51	34.5

Comments. 1. During exposure the rats experienced symptoms similar to those seen during batch tests. Some experienced short breathing and convulsions. These symptoms were most prominent when ignition ceased due to clogging of auger guide.

2. No significant necropsy findings.

Test 3.

Constraints. Aerobic, continuously-fed, auger, crossfire air. Afterburner turned off after first hour of exposure.

Primary Furnace Temperature. 1430°F.

Afterburner Temperature. 1600°F initially.

Air/Fuel Ratio. 550% T.A.

Fuel Consumption rate. 150 gms/hour.

Length of test. Six hours burning time.
Three hours exposure time.

Combustion Results. Visibly the same as in test #2. No flyash determination.

Chemical Results.

Afterburner Temp.	Chemical	Mole fraction (ppm - equivalent methane)
1600°F	CH_4	0.4
	Unknown #1	0.2
1400°F	CH_4	13.1
	C_2H_2	15.9
	C_2H_4	15.3
	Acrolein	3.7
	Pentene	1.3
	Unknown #2	0.8

No HCN as yet.

Test 3.

Chemical Results continued.

Afterburner Temp.	Chemical	Mole fraction (ppm - equivalent methane)
1200°F	CH_4	15.0
	C_2H_2	20.6
	C_2H_4	16.2
	Unknown #3	1.5
	Propylene	1.3
	Acetaldehyde	0.6
	Unknown #1	0.5
	Acrolein	4.3
	Propionaldehyde (tentative)	0.4
	Pentene	1.1
	Unknown #4	3.5
	Unknown #2	0.7

2.0 ppm HCN.

Afterburner Temp.	Chemical	Mole fraction (ppm - equivalent methane)
1000°F	CH_4	19.7
	C_2H_2	13.5
	C_2H_4	12.0
	Unknown #3	2.3
	Propylene	3.2
	Acetaldehyde	~0.1

Test 3.

Chemical Results continued.

Afterburner Temp.	Chemical	Mole fraction (ppm - equivalent methane)
1000°F (cont.)	Unknown #1	0.6
	Acrolein	4.6
	Propionaldehyde (tentative)	0.6
	Pentene	1.4
	Unknown #5	4.2
	Unknown #4	5.7
	Unknown #6	2.1
	Unknown #2	1.4
	9.6 ppm HCN.	
800°F	CH_4	26.5
	C_2H_2	18.7
	C_2H_4	17.1
	Unknown #3	3.0
	Propylene	2.0
	Unknown #1	0.4
	Unknown #7	10.8
	Acrolein	3.9
	19.5 ppm HCN.	

Test 3.

Biomonitoring Results. Plants did not show any wilting until 1400°F. Mustard and alfalfa were most sensitive. When the afterburner reached 1200°F all the plants were affected, in spite of the 10:1 dilution ratio. Animals initiated rapid breathing and general nervousness by 1300°F and were experiencing convulsions by 1200°F. Necropsies showed significant lung changes. Histological examination indicated acute bronchitis.

Tests 4 & 5.

Constraints. Anaerobic, continuously-fed, auger, crossfire air.

Primary Furnace Temperature. 1400°F.

Afterburner Temperature. 1400°F.

Air/Fuel Ratio. 600% T.A.

Fuel Consumption rate. 90 gms/hour.

Length of test. Six hours burning time each test.
Three hours exposure time each test.

Combustion Results.

Flame. Fair to poor. Initially difficult to establish consistent ignition. During exposure, attachment location changed from place to place.

Feeding difficulties. None.

Flyash. Total 0.319 mg flyash/gm fuel.

Distribution

Plate		mg/gm
1	(>9.2μ)	0.0282
2		0.0543
3		0.0655
4		0.0815
5		0.0588
6		0.0135
7	(<0.3μ)	0.0225

Tests 4 & 5.

Chemical Results. 20 ppm HCN plus small amounts of seven hydrocarbons.

Biomonitoring Results. (Dilution; air: effluent = 8.)

Plants. Not tested.

Rats.

Number of control rats.	Two.
Number of exposed rats.	Nine.
Length of exposure.	Three hours.

Blood Work

Function	Hb(g/100 ml)	% CO	W.B.C.	Hematocrit	MCHC
Pre test	16.7 ± 0.3	0	16,400 ± 2,500	48.8 ± 1.3	34.2 ± 1.0
Test	16.0 ± 0.4	5.5 ± 0.6	11,600 ± 3,000	46.0 ± 2.2	35.0 ± 1.2
Control	16.2	0	19,400	47.0	35.5

Enzymes

	SGOT	SGPT
Exposed	88 ± 20	25 ± 12
Control	124	46

Comments. 1. No significant necropsy findings.

Test 6.

Constraints. Aerobic, continuously-fed, pneumatic feed.

Primary Furnace Temperature. 1100°F.

Afterburner Temperature. 1400°F.

Air/Fuel Ratio. 220% T.A.

Fuel Consumption rate. 465 gms/hour.

Length of test. Six hours burning time.

Combustion Results. Air auger produced excellent turbulence. Finally able to obtain fairly stable flame at reasonable A/F ratios. Continuous ignition.

Chemical Results. No peaks above 0.1 ppm on G.C.-F.I.D.

Test 7.

1. Form. Powdered glue. Cascomel MU 7133*. Courtesy of Borden's, Inc.

2. Proximate Analysis.

Moisture	24%
Volatile	65%
Fixed Carbon	9%
Ash	2%

3. Nature of residue. 43% volatile. No fixed carbon.

4. C, H, N analysis.

   C - 33.8%

   H - 4.8%

   n - 30.7%

5. Air/fuel values at 100% theoretical air.

$$\frac{\text{Moles of air}}{\text{mole of plastic}} = 14.6$$

$$\frac{\text{ft}^3 \text{ of air}}{\text{gm of fuel}} = 0.124$$

Assumptions. 1. p = 76 cm, T = 20°C at point of air flow rate measurement.

2. Assume 28.6% of material (by weight) is oxygen available for combustion.

*This material is not, strictly speaking, a "urea"-formaldehyde. Its composition and incineration behavior resemble urea-formaldehyde, rather than other major N- containing resins. The only test being reported here is for off-optimum testing. This material appeared to be not hazardous when afterburner temperatures were kept above 1500°F.

Test 7.

Constraints. Aerobic, continuously-fed, pneumatic feed. Afterburner turned off after nearly three hours exposure time to check off-optimum conditions.

Primary Furnace Temperature.	1150°F.
Afterburner temperature.	1750°F initially.
Air/Fuel Ratio.	150% T.A.
Fuel Consumption rate.	375 gms/hour.
Length of test.	Six hours burning time. Three hours exposure time.

Combustion Results.

Flame. Continuous, turbulent, not attached.

Feeding difficulties. Would not feed in auger, but fed with no difficulty in the pneumatic system.

Flyash. Total 0.241 mg flyash/gm fuel.

Distribution

Plate		mg/gm
1	(>9.2μ)	0.0120
2		0.0075
3		0.0080
4		0.0072
5		0.0187
6		0.0613
7	(<0.3μ)	0.1259

Test 7.

Comments. 1. Plates #6 and #7 were moist. Weight includes some of that moisture.

2. These plates smelled of ammonium bicarbonate.

3. While removing the plates from the hot Andersen to the dessicator prior to weighing, spire-like growths up to ¼" high developed on plates #6 and #7. Their growth took about 30 seconds and appeared to be due to a spontaneous recrystallization upon cooling.

Chemical Results. Qualitative results : some chloride and ammonium. Relatively high cyanide. Quantitative results : 6.5 ppm NO_x present. (These measurements all made after afterburner turned off.)

Biomonitoring Results. (Dilution; air: effluent = 7.)

Plants. For first 2½ hours, no effects observed. When afterburner had dropped to about 1300°F, the plants were becoming slightly darker and wilting. After another hour they were removed. They still had their color but were dead by the next day.

Rats.

Number of control rats.	Two.
Number of exposed rats.	Four.
Length of exposure.	Three hours.

Test 7.

Blood Work

Function	Hb(g/100 ml)	% CO	W.B.C.	Hematocrit	MCHC
Pre test	17.3 ± 0.8	0.6 ± 0.6	15,900 ± 3,600	51.5 ± 2.5	33.4 ± 1.2
Test	17.3 ± 0.8	7.9 ± 5.0	12,300 ± 3,500	50.8 ± 4.6	34.8 ± 2.4
Control (average)	17.7	0	12,500	52.5	33.7

Enzymes

	SGOT	SGPT
Exposed	130 ± 10	48 ± 20
Control	114	26

Comments. 1. No behavioral changes in rats for about 2 3/4 hours - until afterburner reached about 1400°F. Their behavior became excited, with an increase in respiration rate. Some spastic motions, then convulsions and coma. From the first evidence of excitation it was only about 10 minutes before all exposed rats were in coma. They were removed immediately to avoid death.

Necropsy Results. All rats, including controls, had pale and enlarged lungs, which contained a white sudsy mucoid substance. The G.I. tract of three exposed rats were abnormal; the G.I. tract of the first was distended with gas and a thick, sudsy, mucoid substance. The stomach of one rat had a curd-like, white, mucoid substance adherring to the walls, with traces of bile and/or blood. The third had a dark red, raised, "blood blister" on the mucosal surface. The fourth exposed rat had no G.I. tract abnormalities.

Histology - pathology indicated acute bronchitis. It is quite possible that this accounts partially for the severity of reaction.

Test 8.

1. Form. Powdered glue. Casco Urea 5H*. Courtesy of Borden's.

2. Proximate Analysis.

Moisture	10%
Volatile	79%
Fixed Carbon	6%
Ash	5%

3. Nature of residue. More tars present than with other materials.

4. C, H, N analysis.

C - 31.1%

H - 5.3%

N - 24.4%

5. Air/fuel values at 100% theoretical air.

$$\frac{\text{Moles of air}}{\text{mole of plastic}} = 12.8$$

$$\frac{\text{ft}^3\text{ of air}}{\text{gm of fuel}} = 0.108$$

Assumptions. 1. $p = 76$ cm, $T = 20°\text{C}$ at point of air flow rate measurement.

2. Assume 34% (by weight) is bound oxygen available for combustion.

*This material is described as a urea, urea-formaldehyde combination. It is included in the urea-formaldehyde section rather than the urethane section by an equal a priori, random selection process (a flip of a coin).

Test 8.

Constraints. Aerobic, continuously-fed, auger with underfire air.

Primary Furnace Temperature.	1300°F average.
Afterburner Temperature.	1800°F.
Air/Fuel Ratio.	120% to 170% T.A.
Fuel Consumption rate.	600 gms/hour average.
Length of test.	Six hours burning time. Four hours exposure time.

Combustion Results.

Flame. Not always well ignited. Good turbulence. Seldom attached. Much sparking, which indicated not enough time in the primary furnace.

Feeding difficulties. Erratic feed. Probably too high an air flow for this fuel.

Flyash. Total 0.183 mg flyash/gm fuel.

Distribution

Plate		mg/gm
1	(>9.2μ)	0.099
2		0.015
3		0.019
4		0.016
5		0.019
6		0.008
7	(<0.3μ)	0.007

Test 8.

Chemical Results.

Chemical	Mole fraction (ppm)
CH_4	6.0
C_5 Compound	5.0
NO	7.7
NO_2	65
If wood chips were added:	
NO	1.2
NO_2	11.6

Qualitative Analyses. From water traps associated with particulate measurement. Significant quantities of chloride and ammonium. Trace of cyanide.

Biomonitoring Results. (Dilution; air: effluent = 10.)

Plants. No effects observed.

Rats.(Female)

Number of control rats.	Four.
Number of exposed rats.	Six.
Length of exposure.	Four hours.

Test 8.

Blood Work

Function	Hb(g/100 ml)	% CO	W.B.C.	Hematocrit	MCHC
Pre test	15.8 ± 1.5	2 ± 2	14,900 ± 4,800	48.8 ± 2.0	35.0 ± 2.0
Test	15.8 ± 1.6	2 ± 2	10,400 ± 3,000	49.0 ± 3.5	32.4 ± 3.3
Control (average)	17.2	0	12,000	53	34.1

Enzymes

	SGOT	SGPT
Exposed	75 ± 17	18 ± 5
Control	129	22

Urinalysis

	Color	Vol. (ml)	pH	Protein (mg/100 ml)	Sugar	Ketone	Bilirubin	Blood
Pre test	Cl. LS-S.	6.8	6.13	0	0	0	0	0
Test (4)	Cl.S.	9.7	6.2	0	0	0	0	0
Control(2)	Cl.S.	3.5	6.0	0	0	0	0	0

Test 8.

Examination of Sediment Average/HPF

	RBC	WBC	Epith. Cells	Bact.	Casts	Crystals	Comments
Pre test	0.5	0.2	0	2+	0	6 TRP 12 uric acid	
Test	0	4	2.5	3+	0	16 TRP 4 Ca OX	presence of protozoa occ. pin worms
Control	1-2	3	0.5	3+	0	20-25 TRP 5-10 uric acid	occ. protozoa & pin worms

Necropsy Findings. No significant findings.

APPENDIX XIII

Polyvinyl Chloride

1. Form. PVC flour. Courtesy of Union Carbide.

2. *Proximate Analysis.

*Proximate Analysis.	Moisture	0%
	Volatile	96.5%
	Fixed Carbon	1.2%
	Ash	2.3%

3. Nature of residue. None present for continuous burns.

4. C, H, N analysis.

C - 38.4%

H - 4.8%

N - 0%

5. Air/fuel values at 100% theoretical air.

$$\frac{\text{Moles of air}}{\text{mole of plastic}} = 11.9$$

$$\frac{\text{ft}^3 \text{ of air}}{\text{gm of fuel}} = 0.140$$

Assumptions. 1. $p = 76$ cm, $T = 20°C$ at point of air flow rate measurement.

2. All chlorine consumed in reactions with hydrogen.

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*The fixed carbon and ash values represent the char left if PVC is heated in air. If volatilized first and then the residue is exposed to air while at high temperature, the values will be: fixed carbon = 3.5%, ash = 0% (within experimental error).

Test 1. (This test is typical of 10 batch tests on PVC.)

Constraints. Batch burning. 25 gm. samples placed 12" from bottom of afterburner. Crucible not capped.

Primary Furnace Temperature. --

Afterburner Temperature. 1450°F.

Air/Fuel Ratio. about 300% T.A.

Combustion Results. Very slow to ignite. Tenuous flame attached to crucible lip after ignition. Took about two minutes for ignition, then, very slow burning. Burn lasted eight to eleven minutes. Crucible achieved temperature only about 300°F above its ambient.

Effluent was first fog-white, and then pitch black. Both the fog and the soot seemed to form as the effluent cooled outside the furnace.

Chemical Results. Measurements by GC - FID

Chemical	besides total chloride (assumed to be HCl.) Mole fraction (ppm)
One minute before ignition:	
Unknown (including methane)	off scale (>400 ppm)
Ethylene	off scale
Ethane	1.4
Isobutylene	2.5
C_3 Compounds	17.0
C_4 Compounds	4.5

Test 1.

Chemical Results continued.

Chemical	Mole fraction (ppm)
Three minutes after ignition:	
Unknown (including methane)	43
Ethylene	7.9
Ethane	3.0

Comments. 1. Carbon monoxide not measured.

Biomonitoring Results. (Dilution; air : effluent = 4.)

Plants. One week-old plants wilted and were completely yellowed in about one-half minute. (Valve to exposure chamber opened about one minute before ignition.) Two week-old plants were yellowed and wilted, but often recovered later. (Mustard always died.)

Rats. (Only two batch tests involved rats.)

Number of control rats.	Two.
Number of exposed rats.	Four.
Length of exposure.	Three batches of PVC, separated by five minutes of cleaned air - one hour overall exposure.

Test 1.

Blood Work

Function	Hb(g/100 ml)	% CO	W.B.C.	Hematocrit	MCHC
Pre test	16.9 ± 0.1	0	16,000 ± 1,700	52.0 ± 0.3	32.5 ± 0.2
Test	17.3 ± 0.3	6.4 ± 3.8	14,500 ± 2,300	55.8 ± 0.4	31.1 ± 0.8
Control	16.2	2	14,600	52	

Enzymes

	SGOT	SGPT
Exposed	74 ± 11	48 ± 13
Control	83	40

Gross observations immediately after exposure:

Exposed rats experienced a tearing of the eyes, which in some cases was bloody, a clouding of the corneal surfaces, a nasal discharge, and a moist gray-green discoloration of the ventral body surface. Eyes, and nose were reddened. There was also a swelling of the feet, occurrence of lesions and the skin became reddened. The rats appeared to be gagging as they inhaled the fumes. They also would try to wash themselves constantly during the exposure.

Necropsy Findings. One rat was necropsied after exposure. Lungs had a gray mottled discoloration. There was phlegm in the teachea and traces of soot in it. Both eyes had a milky, translucent coating of the corneal at time of bleeding which had begun to clear in the 1 hour elapsed time til necropsy. The small intestines were filled with gas

Test 1.

and a green, sudsy mucoid substance. The cecum had a 2 mm area on the serosal surface which was dark red and appeared like blood trapped between 2 thin layers of tissue.

The other three rats we necropsied 24 hours later. The lungs of all exposed rats appeared to be abnormal, displaying discoloration and occasional areas of hemorrhage. One rat had a dark red area on the gastric portion of the stomach (the mucosal surface), which was 1½ mm in diameter.

No remarkable findings in control rat.

Test 2.

Constraints. Aerobic, continuously-fed, pneumatic feed.

Primary Furnace Temperature.	1500°F.
Afterburner Temperature.	1000°F.
Air/Fuel Ratio.	300% T.A.
Fuel Consumption rate.	200 gms/hour.
Length of test.	Six hours burning time. Four hours exposure time.

Combustion Results.

Flame. Good turbulence, much sparking, ignition generally good. No clear region of attachment.

Feeding difficulties. Some clogging of pneumatic feed.

*Flyash. Total 0.202 mg flyash/gm fuel.

Distribution

Plate		mg/gm
1	(>9.2μ)	0.083
2		0.016
3		0.012
4		0.015
5		0.017
6		0.019
7	(<0.3μ)	0.040

*This measurement is not very meaningful for two reasons. (A) The aluminum of the flyash analyzer contributed to the collected sample

Test 2.

through the formation of aluminum chloride. (B) The flyash contained much very fine and light soot which carried past the last plate and into the water trap. (There is a possiblility that some of this may even have formed within the trap itself.)

Chemical Results. The effluent was first passed through a 0.1 molar NaOH trap, after which it was found that no hydrocarbon peaks >0.1 ppm were present (G.C. - F.I.D.). The Andersen sampler water bath contained 5.53% chloride.

Biomonitoring Results. (Dilution; air: effluent = 7.)

Plants. Both one week-old and two week-old plants were wilted to a brown color within three hours. No recovery for any plants.

Rats.

Number of control rats.	One.
Number of exposed rats.	Four.
Length of exposure.	Four hours.

Test 2.

Blood Work

Function	Hb(g/100 ml)	% CO	W.B.C.	Hematocrit	MCHC
Pre test	17.3 ± 0.2	3 ± 2	12,700 ± 2,600	47.2 ± 0.6	36.6 ± 0.4
Test	16.9 ± 0.8	18.8 ± 9.0	6,300 ± 500	49.5 ± 1.4	34.2 ± 1.7
Control	16.2	3.7	10,500	44.0	36.8

Enzymes

	SGOT	SGPT
Exposed	84 ± 17	32 ± 11
Control	51	17

Observations made immediately after test. Control rat appeared to be normal. Exposed rats - Symptoms varied between animals. However, in general there was a reddening of the eyes, nose, and feet. Edema and Alopecia was found on fore and hind feet. There was a wet coating (brownish - red) over the mouth, chin, and ventral surface of the rats.

Necropsy Findings. Lungs of all control rats were a salmon color, versus the pale ones of the control rats. G.I. tract not examined.

Test 3.

Constraints. Aerobic, continuously-fed, pneumatic feed.

Primary Furnace Temperature.	1600°F.
Afterburner Temperature.	1300°F.
Air/Fuel Ratio.	620% T.A.
Fuel Consumption rate.	250 gms/hour.
Length of test.	Six hours burning time. Four hours exposure time.

Combustion Results.

Flame. Very poor. Sputtering flame due to high air flows. Local ignition regions.

Feeding difficulties. None.

Flyash. Total 0.044 mg flyash/gm fuel.

Distribution

Plate		mg/gm
1	(>9.2μ)	0.005
2		0.001
3		0.001
4		0.005
5		0.008
6		0.008
7	(<0.3μ)	0.016

Test 3.

Comments. Difficulties with flyash measurement not as severe as in Test 2.

Chemical Results. (NaOH trap again used to remove HCl prior to GC analysis.)

Chemical	Mole fraction(ppm)
CH_4	0.7

No other hydrocarbon peaks detected.

Qualitative Analyses . From water traps associated with particulate measurement. Contained about 0.5% chloride (by weight).

Biomonitoring Results. (Dilution; air: effluent = 8.)

Plants. Not tested.

Rats.

Number of control rats.	One.
Number of exposed rats.	Four.
Length of exposure.	Four hours.

Test 3.

Blood Work

Function	Hb(g/100 ml)	% CO	W.B.C.	Hematocrit	MCHC
Pre test	17.2 ± 0.3	0	16,800 ± 2,600	53.0 ± 0.6	32.4 ± 0.5
Test	16.9 ± 0.4	25 ± 13	9,100 ± 2,100	54.3 ± 0.7	31.1 ± 0.6
Control	16.7	0	12,000	49.0	34.1

Enzymes

	SGOT	SGPT
Exposed	102 ± 102	41 ± 12
Control	83	35

Comments. 1. Observations made immediately after test: Reactions were very severe, as they had been for the batch test. Symptoms similar to those obtained from batch testing. In addition, two exposed rats developed wheeze and "rattle" in their chests.

2. One exposed rat was necropsied immediately after test. The control and one of the exposed were necropsied the next day. Two exposed rats were necropsied one week later.

Test 3.

Control rat had no significant findings. Severity of symptoms decreased with time. The exposed rat necropsied immediately after test had a SGOT of 246 and a SGPT of 56. All the rest of the SGPT values were between 33 and 37. The rats necropsied one week after exposure had SGOT values of 23 and 27.

Necropsy Findings. Lungs - slight to marked degrees of hemorrhaging.

Mesentery - reddened in several rats.

Kidneys - several rats showed reddening of the renal pelvis; moderate to marked reddened papillas.

Fatty Tissue - color change varied from pink to red at a variety of locations.

Eyes - clouded corneal surfaces.

Test 4.

1. Form. 50% PVC plus 50% mustard seeds.

2. Proximate Analysis.

Moisture	3.5%
Volatile	86%
Fixed Carbon	8.5%
Ash	2%

3. Nature of residue. Contained 2.3% (by weight) Cl^- .

4. Air/fuel values at 100% theoretical air.

$$\frac{ft^3 \text{ of air}}{\text{gm of fuel}} = 0.150$$

at p = 76 cm, T = 20°C
at point of air flow
rate measurement.

Constraints. Aerobic, continuously-fed, pneumatic feed.

Primary Furnace Temperature.	1600°F.
Afterburner Temperature.	1800°F.
Air/Fuel Ratio.	150% T.A.
Fuel Consumption rate.	460 gms/hour.
Length of test.	Six hours burning time. Four hours exposure time.

Test 4.

Combustion Results.

Flame. Quite good. Continuous ignition. Good turbulence.

Feeding difficulties. None.

Flyash. Total 0.218 mg flyash/gm fuel.

Distribution

Plate		mg/gm
1	(>9.2μ)	0.073
2		0.016
3		0.013
4		0.001
5		0.010
6		0.040
7	(<0.3μ)	0.065

Comments. Again the flyash measurement is probably in error. There were obvious quantities of aluminum chloride present. However, no carryover to water trap as in previous test. This trap was clean.

Chemical Results.

Chemical	Mole fraction (ppm)
NO	3.00
NO_2	0.33
Aldehyde-ketone	<1
Chloride (in effluent)	800

Test 4.

Qualitative Analyses. From water traps associated with particulate measurement. High chloride. No cyanide or ammonium.

Comments. Chloride measurement (in effluent) low for two reasons. (A) Much of the chloride was tied up by the ash-residue, furnace metal, and flyash. (B) There was moisture condensation in the transfer lines.

Biomonitoring Results. (Dilution; air: effluent = 10.)

Plants. After ½ hour of exposure the plants (one week-old and two week-old) were badly wilted. After four hours the plants were completely brown. No recovery.

Rats.

Number of control rats.	Two.
Number of exposed rats.	Six.
Length of exposure.	Four hours.

Blood Work

Function	Hb(g/100 ml)	% CO	W.B.C.	Hematocrit	MCHC
Pre test	17.9 ± 1.2	0	19,800 ± 3,400	51.6 ± 2.6	34.7 ± 1.4
Test	18.1 ± 1.7	0	9,500 ± 1,000	57.5 ± 4.4	31.6 ± 1.7
Controls (2)	16.4	0	11,400	51	32.2

Test 4.

Urinalysis

	Color	(18 hr.) Vol.	pH	protein (mg/100 ml)	Sugar	Ketone	Bilirubin	Blood
Pre test	Cl.S.	12.1	6.3	Trace	0	0	0	0
Test	Cl.S.	6.1	6.0	1+	0	0	0	0
Control	Cl.S.	9.0	7.5	4+	0	0	0	0

Microscopic Examination of Sediment (average/HPF)

	RBC	WBC	Epith. Cells	Bact.	Casts	Crystals	Comments
Pre test	0	1	5.3	4+	+	3 Uric Acid 1 Calcium Oxalate Many Triple Phosphate	1 epitheleal cast 5 sperm
Test	1	25	8.5	4+	+	17 Triple Phosphate 5 Uric Acid	11 Casts Finely or coarsely granular
Control	0	0	0	4+	0	Many Triple Phosphate	4 sperm

Urinalysis results considered abnormal due to number of casts observed in exposed rats.

Necropsy Results. All exposed rats displayed physical changes (during test) the same as seen in all PVC exposures. Controls were normal. Internal damage considerably less than in previous PVC exposures. There were several mottled lungs and raised lymph follicles in GI tract. No other significant findings.

Comments. Differential counts : normal. RBC morphology normal.

APPENDIX XIV

Mixture of Plastics

1. Form. Mixture of plastics compiled from previously tested individual plastics.

2. Proximate Analysis.

Moisture	5%
Volatile	83%
Fixed Carbon	10%
Ash	2%

3. Nature of residue. Contained 4.5% (by weight) chloride. It also contained 40% volatile matter and fixed carbon.

4. Air/fuel values at 100% theoretical air.

$$\frac{\text{ft}^3 \text{ of air}}{\text{gm of fuel}} = 0.324$$

at p = 76 cm, T = 20°C
at point of air flow
rate measurement.

5. Composition.

PE	31%
PVC	20%
PS	18.3%
SAN	5%
ABS	5%
PF	5.8%
PP	5.5%
UF-Urethane	4.4%
PC	2.5%
Barex	2.5%

Test 1.

Constraints. Aerobic, continuously-fed, pneumatic-feed through fan of "box" furnace (Figure VI).

Primary Furnace Temperature. 2000°F. (Average at hot end.)

Afterburner Temperature. 1700°F.

Air/Fuel Ratio. 300% to 400% T.A.

Fuel Consumption rate. 2200 gms/hour.

Length of test. Six hours burning time.
Four hours exposure time.

Combustion Results.

Flame. Turbulence patterns similar to pit incinerators. After achieving steady-state conditions, ignition was continuous.

Feeding Difficulties. Fuel was stoked by hand through combustion-air fan.

Flyash. Total 0.103 mg flyash/gm fuel.

Distribution

Plate		mg/gm
1	(>9.2μ)	0.0360
2		0.0200
3		0.0090
4		0.0060
5		0.0100
6		0.0065
7	(<0.3μ)	0.0156

Test 1.

Comments. 1. The odor and visible smoke from this box was difficult to control. The above flyash readings are average readings, not the best, nor the worst.

2. The residue from this test was not collected and analyzed.

Chemical Results.

Chemical	Mole fraction (ppm)
NO_2	2.14
NO	0.67
Aldehyde-ketone	<1 ppm.

Chloride not measured.

Qualitative Analyses. From water traps associated with particulate measurement. High Cl^- concentrations, trace ammonium and cyanide.

Biomonitoring Results. (Dilution; air:effluent = 5.)

Plants. Three-week old plants. All showed gradual wilting during test, but survived and recuperated in greenhouse.

Rats.

Number of control rats.	Two.
Number of exposed rats.	Six.
Length of exposure.	Four hours.

MIX

Test 1.

Blood Work

Function	Hb(g/100 ml)	% CO	W.B.C.	Hematocrit	MCHC
Pre Test	16.4 ± 1.1	0	10,500 ± 3,000	45.1 ± 2.8	33.5 ± 1.0
Test	16.0 ± 1.1	22.5 ± 2	12,300 ± 3,000	50.6 ± 4.0	31.6 ± 3.5
Control (2)	16.1	1	11,800	48	33.5

	SGOT	SGPT
Exposed	141 ± 40	Error in testing. No results.
Control	137	

Urinalysis.

	Color	(18 hr) Vol.	Spec. Grov.	pH	mg/100 ml protein	sugar	ketone	bilirubin	blood
Pre Test	Cl LS	14.5	1.021	6.0	1+	0	0	0	0
Test	Cl LS	17.1	1.015	6.0	1+	0	0	0	0
Control	Cl S	19.0	1.020	6.0	1+	0	0	0	0

Test 1.

Microscopic Examination of Sediment $\frac{\text{Average}}{\text{HPF}}$

	RBC	WBC	Epi. Cells	Bact.	Costs	Crystals	Comments
Pre Test	1.6	1.6	1.6	3+	0	1 Calcium Oxalate 11 Tri phosphate	Occasional Sperm
Test	0	1	0.5	35+	0	6 Calcium Oxalate 11 Tri phosphate 8 Uric Acid	Occasional Sperm
Control	0	1	1	4+	0	Many TRP and Calcium Oxalate	Occasional Sperm

Necropsy Findings. Physical description exposed rats: Sooty, reddened eyes and noses, gray wet discharges on ventral surface.

Necropsy: Lungs were gray and mottled for all exposed rats, controls appeared normal.

Histology: No remarkable findings.

Test 2.

Constraints. Same mixture as in test #1. Aerobic, continuously-fed, pneumatic feed to original primary furnace (Figure I).

Primary Furnace Temperature.	1750°F.
Afterburner Temperature.	1825°F.
Air/Fuel Ratio.	150% T.A.
Fuel Consumption rate.	380 gms/hour.
Length of test.	Five hours burning time. Four hours exposure time.

Combustion Results.

Flame. Continuous ignition. Flame not attached. Good turbulence.

Feeding Difficulties. None.

Flyash. Total 0.0371 mg flyash/gm fuel.

Distribution

Plate		mg/gm
1	(>9.2μ)	0.0026
2		0.0034
3		0.0045
4		0.0047
5		0.0079
6		0.0074
7	(<0.3μ)	0.0066

Test 2.

Comments. Proximate analysis of residue:

Moisture	1.4%
Volatile matter	28.5%
Ash	68.5%
Fixed Carbon (as conjugated hydrocarbons)	1.5%

Chemical Results.

Chemical	Mole fraction (ppm)
NO_2	1.96
NO	1.07
Chloride not measured.	
Aldehyde-ketone	<1 ppm

Qualitative Analyses. From water traps associated with particulate measurement. Trace of chloride, ammonium.

From residue. Chloride - 4.5% (by weight).

Comments. 1. Much chloride tied up in residue and flyash. Again the particulate apparatus formed much Al Cl_3, *in situ*.

2. We were not able to measure CO concentrations, which is most unfortunate in view of the toxicological results.

Test 2.

Biomonitoring Results. (Dilution; air:effluent = 10.)

Plants. Young (one week old) and old (four week old) plants used. The young plants were affected long before the old ones with the young plants already turning brown when the old ones had just started to wilt. However, all of the plants failed to survive after the test.

Rats.

Number of control rats.	Two.
Number of exposed rats.	Six.
Length of exposure.	Four hours.

Blood Work

Function	Hb(g/100 ml)	% CO	W.B.C.	Hematocrit	MCHC
Pre Test	17.3 ± 0.6	0	18,300 ± 2,500	50.5 ± 2.3	34.2 ± 1.20
Test	16.3 ± 9.0	10.5 ± 2.0	10,600 ± 1,000	49.3 ± 1.9	32.8 ± 1.36
Controls (2)	16.3	0	17,850	53	31.6

Urinalysis.

	Color	(18 hr) Vol.	pH	mg/100 ml protein	sugar	ketone	bilirubin	blood
Pre Test	LS	19.5	6.8	1+	0	0	0	0
Test	Straw-L. Am.	7.1	6.3	1+	0	0	0	Small-Mod.
Control	Straw	5.5	6.5	Trace	0	0	0	Small

Microscopic Examination $\frac{\text{Average}}{\text{HPF}}$

	RBC	WBC	Epi. Cells	Bact.	Costs	Crystals	Comments
Pre Test	0	1.6	1.3	4+	0	3 Uric Acid Many TRP	4.3 Sperm
Test	6.5	2	1	3+	0	4 Uric Acid 7.5 TRP	3.5 Sperm
Control	3	2	2	3+	0	5 Uric Acid 5 TRP	3 Sperm

Necropsy findings. Physical observations upon removal from exposure chamber:

1. Slight nasal discharges, slight reddened eyes and small moist patch around chin and mouth.
2. All exposed rats had a definite odor of HCl.

Internal observations. One control rat appeared to have a bladder infection. The other control was normal. Two exposed rats were not necropsied until two weeks after test. The other four, necropsied the day after the test, had minor lung abnormalities. The two rats necropsied later had mauve-purple renal pelvises. One had an unusually darkened renal cortical junction.

Histology. No remarkable findings.

Test 2.

Other Biomonitoring Comments. Differential counts were made immediately after exposure and 18 hours after exposure. No unusual findings other than a low neutrophil count that was also seen in the controls.

Test 3.

Diluted Plastics Mixture

1. Form. Forty percent of this new mixture was the plastics mixture used in tests 1 & 2. The other 60% was mustard seeds.

2. Proximate Analysis.

Moisture	5%
Volatile	83%
Fixed Carbon	10%
Ash	2%

3. Nature of residue. Residue is 15% volatile matter and fixed carbon and contains 4.5% Cl^-.

4. Air/fuel values at 100% theoretical air.

$$\frac{\text{ft}^3 \text{ of air}}{\text{gm of fuel}} = 0.167$$

at p = 76 cm, T = 20°C at point of air flow rate measurement.

Test 3.

Constraints. Aerobic, continuously-fed, pneumatic feed.

Primary Furnace Temperature. 1800°F.

Afterburner Temperature. 1700°F.

Air/Fuel Ratio. 150% T.A.

Fuel Consumption rate. 333 gms/hour.

Length of test. Five hours burning time.

Four hours exposure time.

Combustion Results.

Flame. Flame was very steady. Easily ignited, and remained ignited consistently. Flame had no apparent attachment point; good turbulence, spread throughout primary furnace.

Feeding difficulties. None.

Flyash. Total 0.160 mg flyash/gm fuel

Distribution

Plate		mg/gm
1	(>9.2μ)	0.0550
2		0.0075
3		0.0024
4		0.0006
5		0.0045
6		0.0120
7	(<0.3μ)	0.0748

Test 3.

Comments. Again flyash measurements affected by the formation of a deliquescent gray solid at the collection plates. Probably aluminum chloride. Spire growths appeared on plates #6 and 7. All plates appeared dull gray. The gray material easily washed off.

Chemical Results.

Chemical	Mole fraction (ppm)
Chloride	80
Aldehyde-ketone	<1
NO_2	0.8
NO	1.45

Qualitative Analyses. From water traps associated with particulate measurement. Significant chloride and ammonium.

From residue. 4.5% (by weight) chloride.

Comments. Chloride is too low because of condensation in transfer line.

Test 3.

Biomonitoring Results. (dilution; air: effluent = 8.)

Plants. One week old plants were used in this test. After four hours, the Indian Mustard & Alfalfa had turned brown and the oats showed signs of wilting and had brown spots on the leaves as did the beans & Kentucky Bluegrass. The one young squash plant was sheltered by the oats and failed to show any damage. All plants but the alfalfa and mustard recovered in the greenhouse, but with some permanently damaged leaves.

Rats.

Number of control rats.	Four.
Number of exposed rats.	Six.
Length of exposure.	Four hours.

Blood Work

Function	Hb(g/100 ml)	% CO	W.B.C.	Hematocrit	MCHC
Pre test	16.9 ± 2.1	0	16,300 ± 4,800	52.5 ± 7.0	32.2 ± 0.8
Test	17.2 ± 0.6	2 ± 2	13,700 ± 3,000	50.0 ± 0.9	33.7 ± 0.9
Control	16.9	1.5	16,300	52.5	32.4

Test 3.

Urinalysis

	Color	(18 hr.) Vol.	S.G.	pH	mg/100 ml protein	Sugar	Ketone	Bilirubin	Blood
Pre test	Cl.LS.	13.6	1.0135	6.0	0	0	0	0	Tr-Sm
Test	Cl.S.	7	QNS	6.0	Trace	0	0	0	Mod
Control	Cl.LS.	11.7	1.015	6.0	1+	0	0	0	0

Microscopic Examination of Sediment/HPF

	RBC	WBC	Epith. Cells	Bact.	Casts	Crystals
Pre test	No microscopic performed					
Test	4	1	2	3+	0	5 TRP 3.5 Uric Acid
Control	0	0	0	3+	0	5 UA 10 TRP 15 Calcium oxalate

Necropsy Findings. 3 out of four control rats had no gross lesions. One had pale, spongy lungs. One of the six exposed rats had no gross lesions. The remaining five had lung abnormalities varying from mottled tissue to pale tissue and hemorrhagic blotches. Apparently least effects of any of the mixture tests.

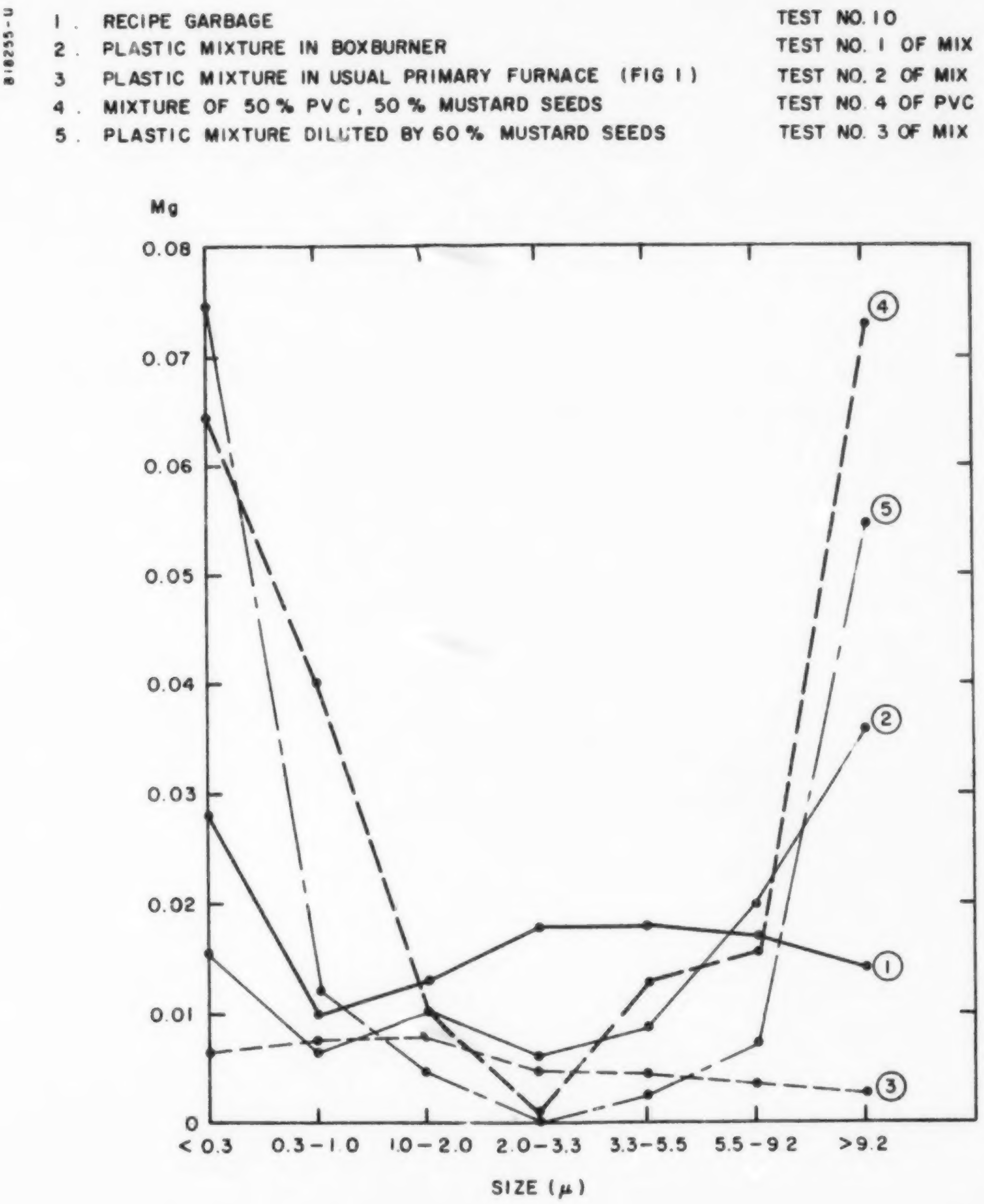

Fig. 8. Flyash distributions for various mixtures.

END

APPENDIX XV

Chronology

The first year was devoted to establishing a tentative protocol for chemical testing and toxicological testing. During this time several furnaces were constructed and preliminary burns were made. Some time was spent in an unsuccessful attempt to concentrate trace gases from the gaseous effluent. A new gas chromatograph was purchased and arrived at the end of this first year. We lost four months or so right at the beginning of actual lab time due to reconstruction of the laboratory area. We required more electricity, water and compressed air than was available in that section of the building, so some major reconstruction was required.

The first two animal chambers were constructed, tested and discarded during this time. The new designs were developed late in this first year. It was during this first year that most of our equipment and supplies were ordered.

The second year was devoted to putting this all together in a workable fashion. In so doing we spent a great deal of time testing polyethylene, polystyrene, occasionally polyvinyl chloride and ureaformaldehyde and some recipe garbage. The toxicological procedures were firmed up during this period of time and we added two personnel to the grant, END

one a consultant and one a technician to carry the bulk of the biomonitoring load. The gas chromatograph purchased during the first year was made operational with a great deal of difficulty (we were fortunate enough to acquire Serial No. 1 of this model) and interfaced with the mass spectrometer that was purchased by the Research Corporation. During this time we developed techniques for dealing with deterioration of furnace elements. Several designs of furnaces were developed, and methods were worked out whereby we could quickly clean various transfer lines between tests of various plastics.

Most of the actual testing was done during the third year. During this period the general trend of our chemical analysis was away from GC-MS, toward "wet" chemistry. To our previous biomonitoring procedures was added a histological - pathological procedure and urinalysis. The final months were concentrated on data compilation, reduction and interpretation. In the process of compiling data several tests became suspect and we repeated them. The last month was spent accomplishing an orderly shutdown of the operation with an eye to the possibility of reopening this type of research in the near future.